# Hydrologic Modeling of the Great Salt Plains Basin

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**Submitted to:** Environmental Protection Agency

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# Executive Summary

## Introduction

On the shores of the Great Salt Plains Reservoir lie 11,000 acres of salt plains, most of which is part of the Salt Plains National Wildlife Refuge. In recent years this area has suffered excessive siltation and nutrient problems which threaten fish and migratory birds.

The basin that feeds the Great Salt Plains Reservoir covers more than 8,000 square kilometers in both Oklahoma and Kansas. The majority of this area is rangeland, but a quarter of the basin is covered in wheat. The purpose of this project is to recommend BMPs (Best Management Practices) for wheat and other agricultural lands in the basin. SWAT is a distributed basin scale water quality model which was used to simulate and compare BMPs.

## SWAT Model Input

GIS (Geographic Information System) data for topography, soils, land cover, and streams were used in the SWAT model. An ArcView GIS interface was used to summarize the GIS data and convert it to a form usable by the model. The most current GIS data available were used in the model (Table 1). Observed precipitation and temperature from 28 stations in and around the basin were included in the model.

| Data Type | Source | Resolution or Scale |
|---|---|---|
| Topography | USGS (US Geological Survey) DEM (Digital Elevation Model) | 30 meters |
| Land Cover | USGS NLCD (National Land Cover Data) | 30 meters |
| Soils | NRCS (Natural Resource Conservation Service) Certified SSURGO (Soil Survey Geographic) | 1:24,000 |
| | NRCS MIADS (Mapping and Information Display System) | 200 meters |
| | NRCS Uncertified SSURGO | 1:24,000 |
| Weather | NOAA Cooperative Observation Network | N/A |

**Table 1** GIS (Geographic Information Systems) data used with the SWAT (Soil and Water Assessment Tool) model.

## Calibration

Calibration is the process by which a model is adjusted to more closely match some observed data. Calibration greatly improves the accuracy of a model. The SWAT model was calibrated on observed streamflow from three USGS gages. Two of these gages had records which cover the entire period of interest 1980 to 2000. The other gage covered 1980 to 1992.

Stream flow has two primary sources, surface runoff and ground water. Ground water contributions to stream flow is known as baseflow. Baseflow was separated from daily stream flow using a method adapted from the USGS program HYSEP (HYdrograph SEParation). The SWAT model was calibrated separately against observed surface and baseflow at the two gages which cover the entire period of interest. The other gage is located downstream the reservoir making baseflow separation impossible; thus it was calibrated for total flow only.

## The Calibrated Model

Because SWAT is a distributed model and operates on a daily time step, it is possible to view model outputs as they vary both spatially and temporally. Model outputs were grouped by land cover and examined. Figure 1 illustrates the contribution of each land cover to the total basin load.

Conclusions drawn from the calibrated model:

- Sediment and nutrient yields vary dramatically across the basin.
- Wheat is the largest source of sediment in the basin.
- Each land cover has unique temporal nutrient and sediment distributions.
- Wheat accounts for 92% of all surface nonpoint source nitrate contributions to ground water.

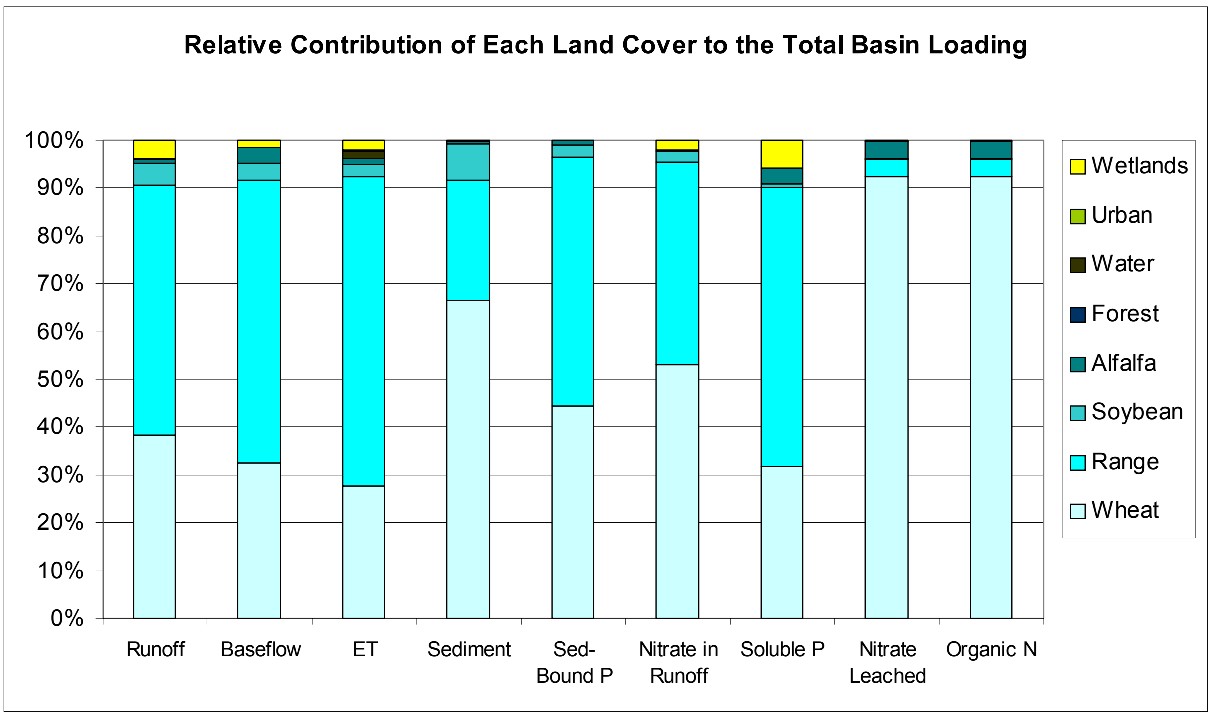


**Figure 1** Relative contribution of each land cover to the total basin load. Derived from a 20-year (Jan 1, 1980 to Dec. 31, 1999) simulation of the calibrated SWAT model.

## BMP Results

Several tillage, harvest type, fertilization, and pesticide BMPs were compared. All comparisons were made strictly on a relative basis since the model was not calibrated for the majority of the outputs examined.

Primary conclusions from SWAT model BMP simulations:

- Splitting fertilizer applications reduced nitrogen losses.
- Switching from moldboard to low till reduced sediment yield by half.
- Harvest type had a greater influence than tillage on soluble nutrients.

Tillage (moldboard plow, stubble mulch, or low till) and harvest type (grazing only, grain only, or grazing and grain) combinations were simulated and compared. Harvest type was more dominant than tillage for most model outputs. However, both had a statistically significant effect on sediment and sediment-bound nutrients.

Several fertilization scenarios and application rates were simulated. The SWAT model indicated split fertilization reduced nitrate yields over a single preplant application. The model also predicted increased nitrogen and phosphorous yields at higher fertilization rates.

Herbicide usage on wheat and insecticide usage on alfalfa were examined. The model indicated insecticide yield dramatically spiked a few times over the period modeled. Presumably due to the short residence time of insecticides and the timing of rainfall events relative to insecticide application. Herbicide yields from wheat show far less year to year variability, presumable due to longer lasting residuals.

## Model Limitations

Model limitation may be the result of data used in the model, inadequacies in the model, or using the model to simulate situations for which it was not designed. Hydrologic models will always have limitations, because the science behind the model is neither perfect nor complete. A model by definition is a simplification of the real world.

Important limitations of the SWAT model:

- Weather data from a few stations may not be representative of the entire area.
- Each HRU in a subbasin is assumed to have the same topographical characteristics.
- Management varies by field, not by crop or category as was assumed.
- Land cover area fractions from the original GIS data cannot be preserved.
- Very small land covers are not represented in the GIS data.

# Introduction

## The Great Salt Plains Reservoir

The Great Salt Plains Reservoir is one of Oklahoma's most unique areas. It is located just west of Cherokee Oklahoma (Figure A1). On the shores of the lake lie 11,000 acres of salt plains, most of which is part of the Salt Plains National Wildlife Refuge. The salt plains and lake are the seasonal home of many migratory birds. This area is an important stopping place for ducks and geese during their migratory trip over the plains.

The salt plains are thought to be a remnant of ocean flooding millions of years ago. These plains are the only place in the world where hourglass shaped Selenite crystals can be found. Selenite crystal is a form of gypsum. These crystals grow just below the salt-encrusted surface. The crystals grow and dissolve with the changes in salinity of the brine that lies under the surface of the salt plains. The lake averages only 4 feet deep and is about half as salty as ocean water. In recent years, siltation has become an increasing problem for the lake and its tributaries. Sediment, pesticides, and nutrients from the rangeland and the wheat fields of Oklahoma and Kansas wash into tributaries that feed the reservoir. Excessive nutrients cause algae blooms that deplete the water of oxygen and kill fish.

## Hydrologic modeling

The watershed covers some 8,000 square kilometers around the Oklahoma-Kansas border. Much of this area is used for farming and grazing cattle. The purpose of this project is to recommend BMPs (Best Management Practices) for agricultural lands in the watershed. Computer modeling was used to simulate and compare BMPs. Soil and Water Assessment Tool (SWAT) is a hydrologic model that was used to predict how management changes effect basin load.


**Figure A1** Location of the Great Salt Plains Reservoir Basin.

# SWAT Input Data

GIS data for topography, soils, land cover, and streams were used in the SWAT model. The data used were the most current at the time of compilation. Observed daily rainfall and temperature data were used in all modeling.

## SWAT Overview

SWAT (Soil and Water Assessment Tool) is a distributed hydrologic model. Distributed hydrologic models allow a basin to be broken into many smaller subbasins to incorporate spatial detail. Water yield and loadings are calculated for each subbasin and then routed through a stream network to the basin outlet. SWAT goes a step further with the concept of HRUs (Hydraulic Response Units). A single subbasin can be further divided into areas with the same soil and land use, these are HRUs. Processes within an HRU are calculated independently. The total yield for a subbasin is the sum of all the HRUs within it. HRUs allow more spatial detail to be included by allowing more land use and soil classifications to be represented for any given number of subbasins.

SWAT is a physically based continuous simulation model that operates on a daily time step. Long-term simulations can be performed using simulated or observed weather data. The relative impact of different management scenarios can be quantified. Management is set as a series of individual operations (e.g., planting, tillage, harvesting, or fertilization).

SWAT is the combination of ROTO (Routing Outputs to Outlets) (Arnold et al., 1995) and SWRRB (Simulator for Water Resources in Rural Basins) (Williams et al., 1985; Arnold et al., 1990). SWAT was created to overcome maximum area limitations of SWRRB, which can only be used on watersheds a few hundred square kilometers in area and less than10 subbasins. SWAT can be used for much larger areas. Several models contributed to SWRRB and SWAT: CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) (Knisel, 1980), GLEAMS (Ground Water Loading Effects on Agricultural Management Systems) (Leonard et al.,1987), and EPIC (Erosion-Productivity and Impact Calculator) (Williams et al.,1984).

## SWAT Input Data

An ArcView GIS interface is available to generate model inputs from commonly available GIS data. These GIS data are summarized by the interface and converted to a form usable by the model. GIS data layers of elevation, soils, and land use are used to generate the input files. Observed temperature and precipitation can be incorporated. If no observed weather data are available, weather can be generated.

## Topography

Topography was defined by a DEM (Digital Elevation Model). DEMs for the United States are available for download via the Internet.[1] The DEM was used to calculate subbasin parameters such as slope, slope length, and to define the stream network. The resulting stream network was used to define the layout and number of subbasins. Characteristics of the stream network, such as channel slope, length, and width, were all derived from the DEM.

Individual 1:24,000 thirty meter DEMS were stitched together to construct a DEM for the entire basin. When tiled, 1:24,000 DEMS often have missing data at the seams. These missing data must be replaced. A 3x3 convolution filter was applied to the DEM to produce a seamless filtered DEM. Any missing data at the seams of the original DEM were replaced with data from the filtered DEM. The resulting seamless DEM retains as much non-filtered data as possible (Figure B1). Filtering tends to remove both peaks and valleys from a DEM thereby reducing the perceived slope. For this reason the use of filtered data were kept to a minimum.

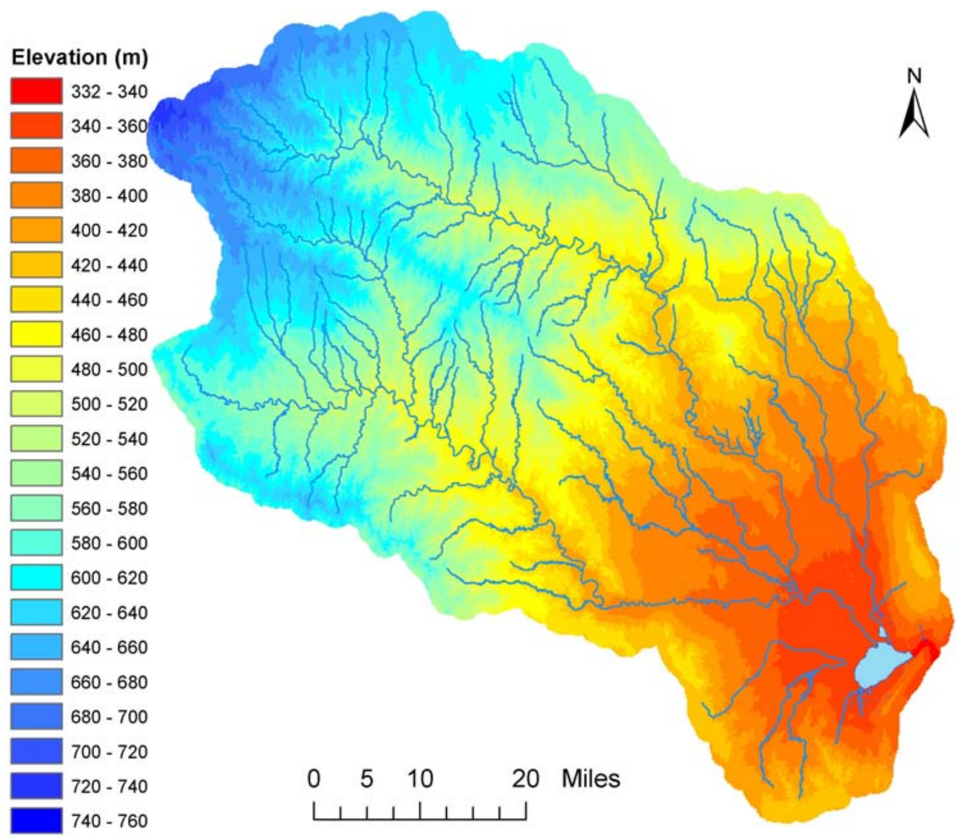


**Figure B1** Digital Elevation Model (DEM) of the Great Salt Plains Basin. Derived from US Geographic Survey 1:24,000 DEMs.

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1 USGS DEMs are available via the web at http://edc.usgs.gov/doc/edchome/ndcdb/ndcdb.html

## Soils

Soil GIS data are required by SWAT to define soil types. SWAT uses STATSGO (State Soil Geographic Database) data to define soil attributes. The GIS data must contain the S5ID (Soils5id number for USDA soil series) or STMUID (State STATSGO polygon number) to link a soil to the STATSGO database.

The soils layer was derived from three separate GIS coverages. The Alfalfa County Oklahoma portion is 200-meter resolution MIADS (Map Information Assembly and Display System) data from the Oklahoma NRCS.[1] The Woods County Oklahoma portion is certified SSURGO (Soil Survey Geographic) soils data from the Oklahoma NRCS. The Kansas portion is 1:24,000 detailed soils digitized by Kansas State University data.[2]

These highly detailed soils data are difficult to use with the SWAT model. The SWAT model has an internal database of soil properties based on STATSGO data. SSURGO data contains soils that are not available in this database. The most similar soils listed in the SWAT database were substituted for these unavailable soils. Similarity was based on soil properties weighted by their relative importance. Only soils with the same hydrologic soil group were considered for substitution. A score from zero to 1000 was given based on the formula:

$$\text{Score} = 1000 - \sum(\text{Relative difference at parameter} * \text{Parameter importance})$$

Parameter importance is given in Table B1. A score of 1000 is a perfect match but any score above 800 is still a fair match (Figure B2). Any soils with matching S5IDs are automatically assigned a score of 1000. A program was written to search all soils in the STATSGO database for Oklahoma, Texas, and Kansas. The ten highest ranking soils were recorded and the best among them was manually selected. An example output from the program is located in the appendix.

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[1] MIADS metadata available form the Oklahoma NRCS via the web at: http://ok.nrcs.usda.gov/gis/text/041_lu.htm

[2] Detailed Soils metadata available from the Data Access and Support Center at: http://webmaps.kgs.ukans.edu/dasc/catalog/coredata.html

**Table B1** Parameter importance used to match SSURGO (Soil Survey Geographic) Soils to the STATSGO (State Soil Geographic) database included with SWAT.

| Parameter | Layer 1 | Layer 2 | Layer 3 | Layer 4 | Layer 5 |
|---|---|---|---|---|---|
| Fine earth fraction | 15 | 10 | 8 | 5 | 2 |
| Permeability low | 10 | 7 | 5 | 4 | 2 |
| Permeability high | 10 | 7 | 5 | 4 | 2 |
| Clay content low | 8 | 6 | 4 | 3 | 2 |
| Clay content high | 8 | 6 | 4 | 3 | 2 |
| Organic matter content low | 8 | 6 | 4 | 3 | 2 |
| Organic matter content high | 5 | 6 | 4 | 3 | 2 |
| Layer depth | 8 | 4 | 4 | 3 | 2 |
| Available water low | 8 | 6 | 4 | 3 | 2 |
| Available water high | 8 | 6 | 4 | 3 | 2 |
| Bulk density low | 7 | 6 | 4 | 3 | 2 |
| Bulk density high | 7 | 6 | 4 | 3 | 2 |
| % passing #4 sieve low | 5 | 4 | 4 | 3 | 2 |
| % passing #4 sieve low | 5 | 4 | 4 | 3 | 2 |
| % passing #200 sieve low | 5 | 4 | 4 | 3 | 2 |
| % passing #200 sieve low | 5 | 4 | 4 | 3 | 2 |

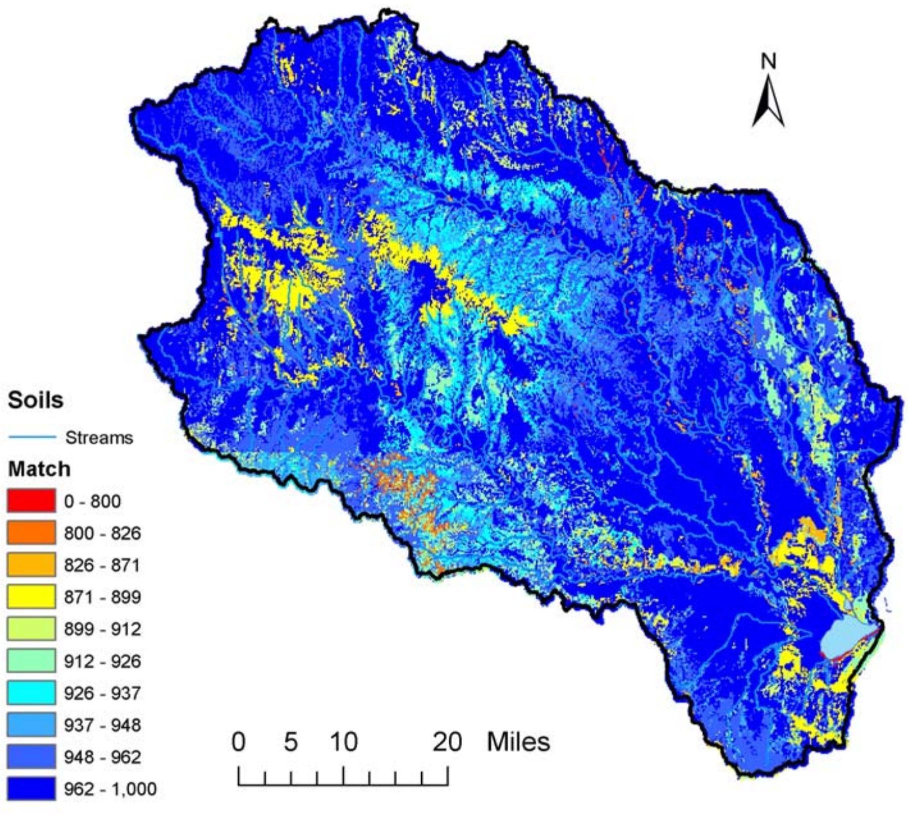


**Figure B2** Results of high detail soils to SWAT soils matching algorithm.

## Land Cover

Land cover is perhaps the most important GIS data used in the model. The land cover theme determines the amount and distribution of wheat and range in the basin. These two land covers are managed very differently. It is important that these data be based on the most current data available since land cover changes over time. Topography and soils cannot be changed so easily or rapidly by man. Land cover was derived from Oklahoma and Arkansas NLCD (National Land Cover Data).[3] The NLCD project mapped vegetation based on 30 meter Landsat Thematic Mapper satellite imagery.

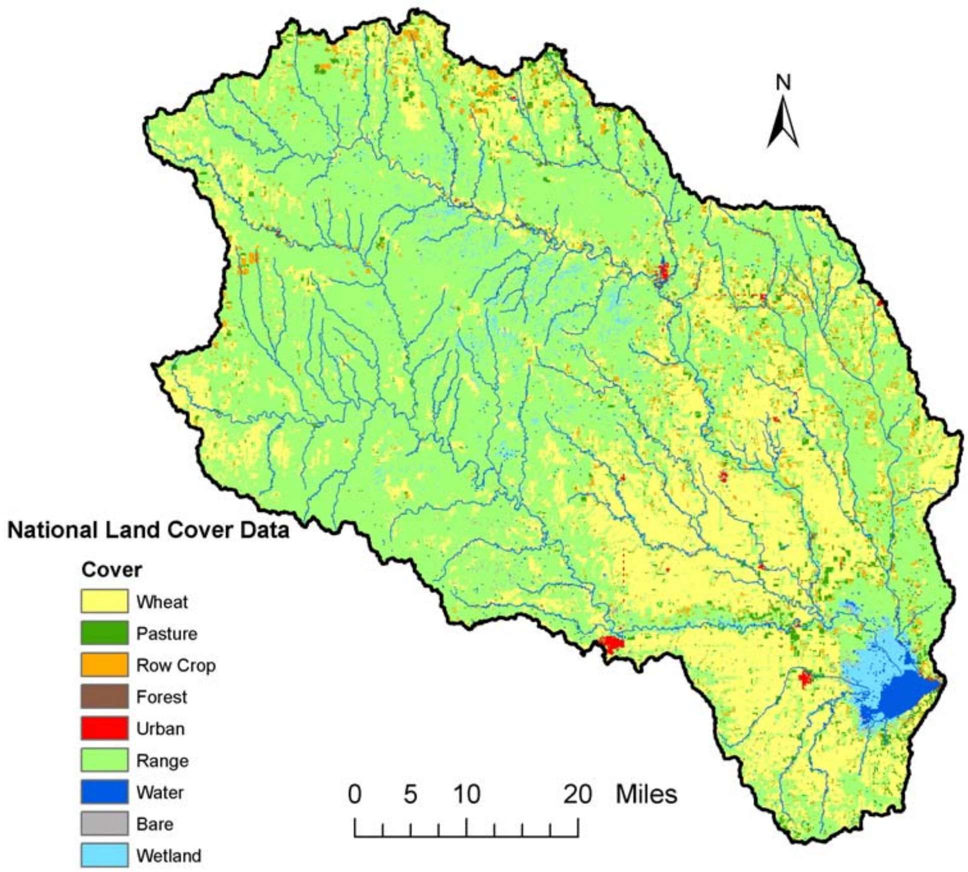


**Figure B3** National Land Cover Data (NLCD) derived land cover for the Great Salt Plains Reservoir basin.

[3] A more detailed description of NLCD data is available online: http://www.epa.gov/mrlc/nlcd.html

## Weather

SWAT can use observed weather data or simulate it using a database of weather statistics derived from stations across the US. Observed daily precipitation and minimum and maximum temperature data were used in the Great Salt Plains model. National Weather Service COOP (Cooperative Observing Network) station data from 28 stations from 1/1/1950 to 12/31/99 were used to in the SWAT model (Figure B4). COOP data are available from the NOAA (National Oceanic and Atmospheric Administration). Average annual precipitation varies by almost six inches across the basin (Figure B5), so it is important to have as many stations as possible.

COOP data are seldom continuous for long periods of time. Missing days and even months are common. The period of record at stations are inconsistent, so the number of active stations changes with time. When SWAT detects missing data at a station, it generates simulated weather. Gaps in a station's record were filled with interpolated data from surrounding stations. Shepherd's weighted interpolation was used because it is computationally efficient.

Shepherd's method uses weighting factors derived from the distance to nearby stations within a fixed radius:

$$Z_0 = \frac{\sum_{i=1}^{n} Z_i W_i}{\sum_{i=1}^{n} W_i}$$

where $Z_0$ is the precipitation at the station of interest in mm, $Z_i$ is the precipitation at station $i$ in mm, and $W_i$ is the weighting factor at station $i$.

Weighting factors are calculated using the distance between stations:

$$W_i = \left(1 - \frac{d_i}{R}\right)^2 \text{ for } \frac{d_i}{R} < 1 \text{ And } W_i = 0 \text{ for } \frac{d_i}{R} \geq 1$$

Where $R$ is the radius of influence in meters and $d_i$ is the distance from station of interest to station $i$ in meters.

Because of the large amount of data associated with these weather files, all processing and formatting was accomplished with custom programs written in VBA (Visual Basic for Applications) and Microsoft Excel. SWAT assigns each subbasin to the closest gage station to the subbasin centroid so many of the original 28 stations were not used by SWAT. The purpose of these extra stations was to fill gaps in records for the stations that were used by SWAT.

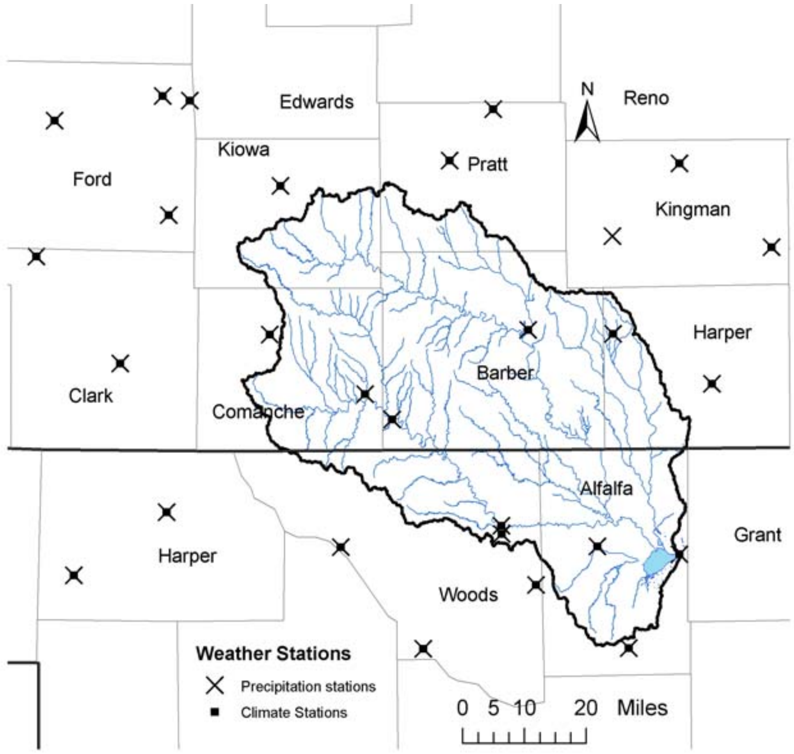


**Figure B4** National Weather Service Cooperative Observation network precipitation and temperature station locations near the Great Salt Plains Reservoir Basin.

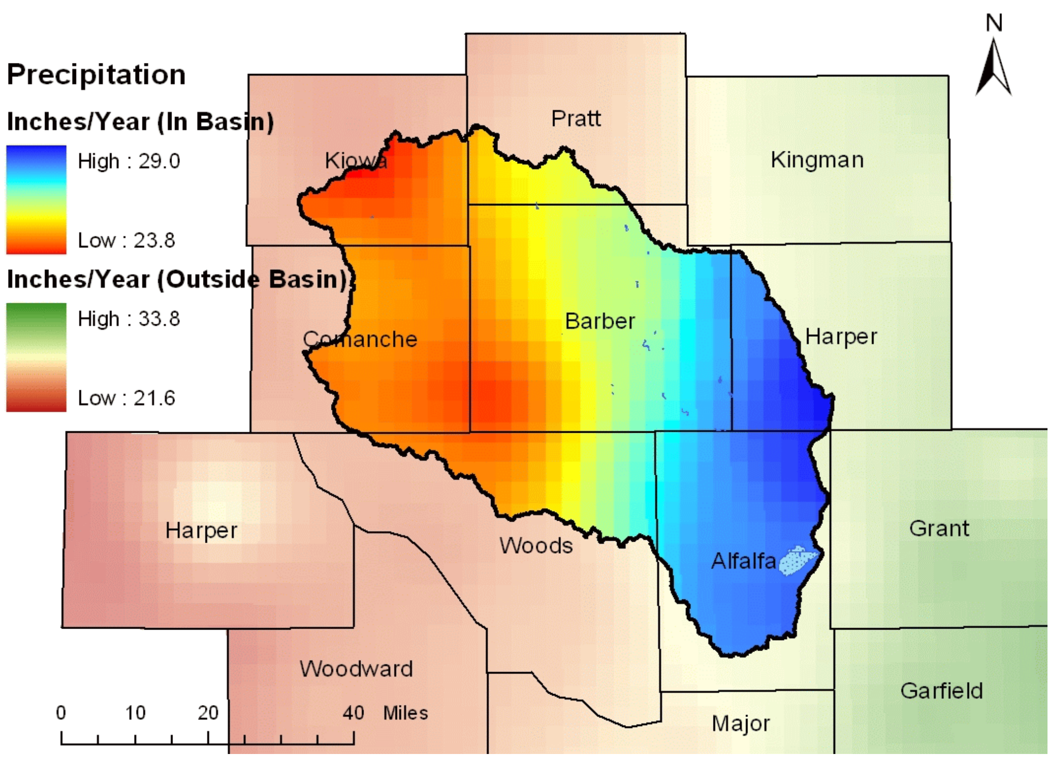


**Figure B5** Precipitation based on PRISM (Parameter-elevation Regressions on Independent Slopes Model) data for the Great Salt Plains Reservoir Basin.

## Subbasin Delineation

The subbasin layout developed was using the DEM, a stream burn in theme, and a table of additional outlets. A stream burn in theme is simply digitized streams. Its purpose is to help SWAT define stream locations correctly in flat topography. A modified reach3 file from the Environmental Protections Agency's BASINS (Better Assessment Science Integrating Point and Non-point Sources) model was used. Model output is only available at subbasin outlets so additional outlets were added at points of interest such as gage stations. A stream threshold value of 1000 ha was used to delineate subbasins. Threshold area is the minimum contributing upland area required to define a single stream. The result is 210 subbasins (Figure B6). Fewer subbasins would simplify the modeling process, but this level of detail was needed to adequately represent the basin[4].

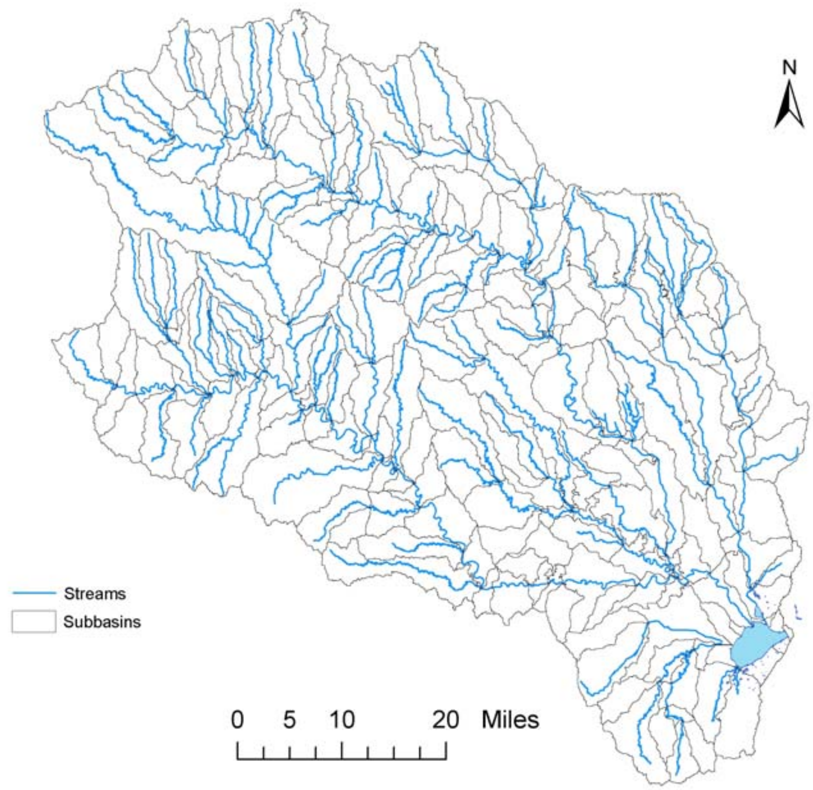


**Figure B6** Subbasin layout used in SWAT model. The Great Salt Plains Reservoir Basin is simulated as 210 subbasins.

[4] Bingner, R.L., Garbrecht, J., Arnold, J.G., and Srinivasan, R., 1997, "Effect of Watershed Subdivision on Simulation Runoff and Fine Sediment Yield."

## HRU Distribution

Each of the 210 subbasins was split into HRUs (Hydraulic Response Units) by SWAT. The *land use [%] over subbasin area threshold* was changed from the default 20% to 3%. This threshold determines the minimum percentage of any land cover in a subbasin that will become an HRU. The *soil class [%] over subbasin area* was also reduced from its default value of 20% to 10%. By reducing these thresholds, the number of HRUs was increased to 2,745, allowing more spatial detail to be incorporated into the SWAT model. The average area of each HRU is 2.97 square kilometers, but there is significant variability in sizes (Figure B7).

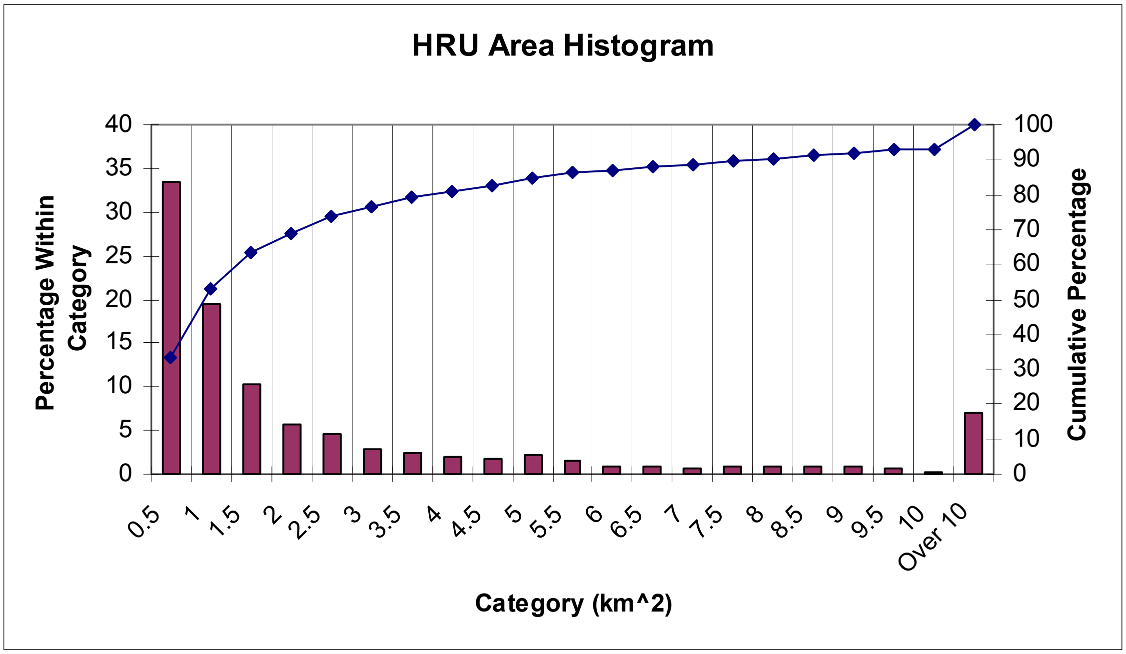


**Figure B7** Histogram of HRU sizes which make up the SWAT representation of the Great Salt Plains Basin.

## Soil Phosphorous Content

Two distinctly different methods were used to estimate soil phosphorus content. Soil phosphorous content for agricultural areas were estimated using observed soil test data. Soil phosphorous content for un-managed range was based on SWAT computer simulations.

### Range - Soil Phosphorous Content

Soil phosphorous estimates for un-managed range areas were based on SWAT computer simulations. A reasonable phosphorous yield for rangeland was considered to be between 0.25 and 1.46 kg P/ha (Beaulac and Reckhow (1982) values for unfertilized grazed bluestem in Chickasha, Oklahoma). A value of 30 lb/acre phosphorous for rangeland areas of the Saltfork calibration area produced a phosphorous yield of 1.1 kg P/ha.

Modifications to soil phosphorous were made using the SWAT input parameter Sol_labp (Labile [soluble] phosphorous concentration in the surface layer, mg/kg). This parameter also sets the amount of phosphorous in SWAT's various phosphorous pools. Sol_labp was assumed to be related to soil test phosphorous by:

**Melich III Soil test P (lb/acre) = 5 sol_labp (mg/kg)**

Additional detail can be found in the appendix.

### Agricultural Crops - Soil Phosphorous Content

Observed Melich III soil test data were used to determine the soil phosphorous content for agricultural areas. County extension agents Bob Devalley, Kevin Sheltion and Tommy Puffenberger provided soil tests from different portions of Alfalfa and Woods counties. Annual county level BRAY II soil test summaries were provided by David Whitney (Extension State Leader Agronomy Program) for the Kansas portion. Summaries from 1995-1999 were averaged to provide estimates of STP for each county in the Kansas portion of the basin. Bray II and Melich III are comparable in the acidic soils which dominate the agricultural portions of the basin (Hailin Zang OSU soil testing lab director, personal communication). These data are mapped in Figure B8. An area weighted soil test phosphorous was calculated for each of SWAT`s 210 subbasins.

We used a specially compiled version of the SWAT model. At our request, Susan Neitsch (SWAT team, user assistance) modified SWAT 99.2 such that the entire soil profile was set to the same soluble phosphorous as the surface layer. The original SWAT 99.2 allows only the soluble phosphorous in the top 10 mm of soil to be set by the user, and the remainder of the soil profile is set to a value of 20 mg P/kg soil. The original SWAT was not very sensitive to changes in soil phosphorous. Adjustments to the phosphorous content of the top 10 mm make little difference to the total amount of phosphorous in the soil profile. Mixing between layers make the phosphorous content of the top 10 mm approach the default value of the layer beneath in a few years.

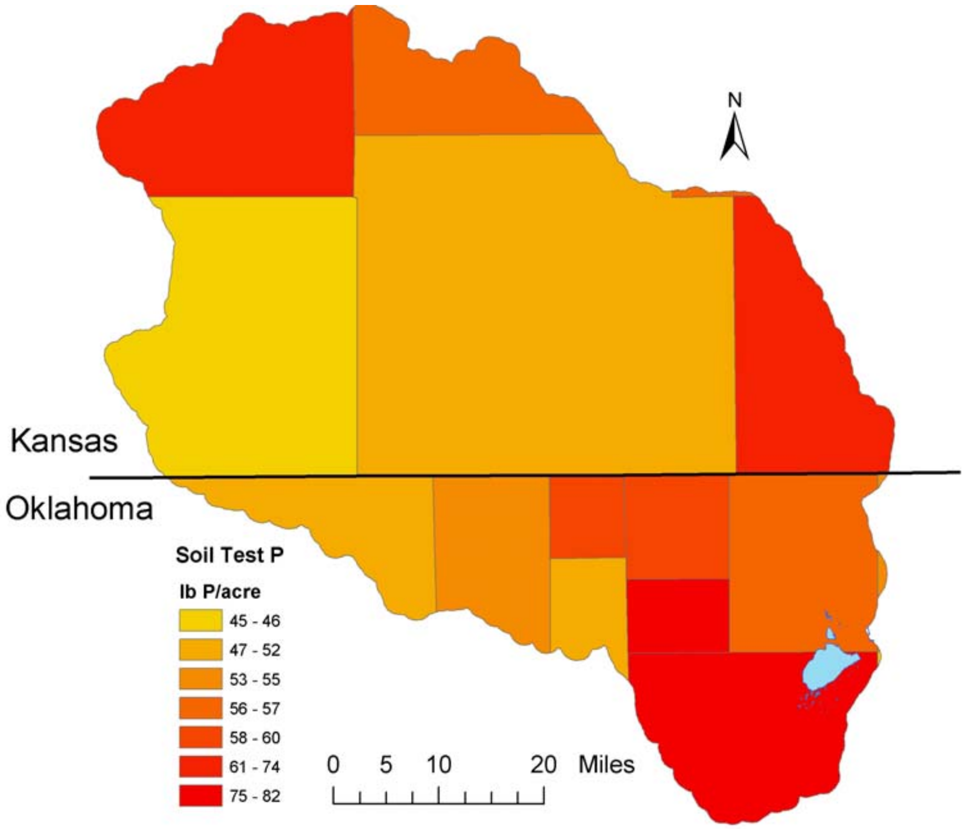


**Figure B8** Soil test phosphorous for agricultural areas derived from soil samples of the Great Salt Plains Reservoir Basin.

## Current Management

The current management was determined from a phone survey of producers in September 1999. Eighty-seven respondents answered a variety of questions about their wheat, sorghum, and alfalfa production. Data from this survey was used to determine how much wheat was used only for grazing, only for grain, or for both (Table B2). Survey information was also used to determine the relative proportion of moldboard plowing, stubble mulch tillage, and low-till wheat in Wood`s and Alfalfa counties.

SWAT defines management as a series of individual operations. The timing of these operations may be defined by a date or as a fraction of the total heat units required by the crop. Heat unit scheduling is the default. All forest, wetland, rangeland, and urban HRUs use the default management generated by the ArcView SWAT interface.

Heat units are accumulated when the average daily temperature exceeds the base temperature of the crop. The base temperature is the minimum temperature required by the plant to grow. The heat units accumulated each day are equal to the average daily temperature minus the base temperature of the plant. When no plant is growing the model uses a base temperature of $0^o$ C and keeps a separate running total. This base $0^o$ running total is used to schedule planting dates because no heat units can be accumulated until plant growth begins.

Wheat grazing was simulated at approximately 0.33 animal units per acre (Oklahoma State University Extension Facts 2855), with 9.35 kg of dry biomass consumed and 2.92 kg of dry manure deposited per hectare (ASAE D384.1). The grazing occurs for a maximum of 100 days. Any time there is less than 600 kg (dry weight) of biomass per hectare grazing is suspended.

Originally, the small grains category from the NLCD was separated into nine categories, each with a different wheat management. Many categories were too small to be represented in the model. The number of wheat management categories was reduced from nine to four. The five deleted categorizes were redistributed among the remaining four based on the area of the remaining categories.

The management of each category is defined by a particular set of operations (Table B3) The individual operations and their timing is based on survey information, and recommended practices for wheat. The goal is not to emulate the actual management, as this varies by field, but to select reasonable management operations for each catagory.

**Table B2** Managements for the Saltfork Basin derived from survey results.

| | Wheat for grain only | | | | Wheat for grazing only | | | |
|---|---|---|---|---|---|---|---|---|
| County | Sub-total | MB plow | Stubble | No till | Sub-total | MB plow | Stubble | No till |
| Alfalfa | 31.2% | 19.6% | 10.1% | 1.6% | 6.5% | 4.1% | 2.1% | 0.3% |
| Woods | 59.7% | 21.5% | 35.2% | 3.0% | 11.0% | 4.0% | 6.5% | 0.6% |

| | Wheat for grazing and grain | | | |
|---|---|---|---|---|
| County | Sub-total | MB plow | Stubble | No till |
| Alfalfa | 62.3% | 39.1% | 20.1% | 3.1% |
| Woods | 29.3% | 10.6% | 17.3% | 1.5% |

**Table B3** Management operations for wheat in the Great Salt Plains Basin.

| Stubble Mulch (Grazing and Grain) | |
|---|---|
| Operation | Date |
| 70 lb/acre Nitrogen (surface) | 1-Feb |
| Harvest | 15-Jun |
| Duckfoot cultivator | 15-Jul |
| 30 lb/acre Phosphorous (surface) | 1-Aug |
| 40 lb/acre Nitrogen (sub-surface) | 15-Aug |
| Disk | 30-Aug |
| Plant Wheat | 1-Sep |
| Grazing .33 Animal unit/acre (100 days) | 1-Nov |

| Moldboard Plow (Grazing and Grain) | |
|---|---|
| Operation | Date |
| 70 lb/acre Nitrogen (surface) | 1-Feb |
| Harvest | 15-Jun |
| Moldboard plow | 15-Jul |
| 30 lb/acre Phosphorous (surface) | 1-Aug |
| Disk | 2-Aug |
| 40 lb/acre Nitrogen (sub-surface) | 3-Aug |
| Disk | 20-Aug |
| Plant Wheat | 1-Sep |
| Grazing .33 Animal unit/acre (100 days) | 1-Nov |

| Moldboard Plow (Grain only) | |
|---|---|
| Operation | Date |
| 40 lb/acre Nitrogen (surface) | 1-Feb |
| Harvest | 1-Jul |
| Moldboard plow | 15-Jul |
| 30 lb/acre Phosphorous (surface) | 10-Aug |
| Disk | 11-Aug |
| 40 lb/acre Nitrogen (sub-surface) | 11-Aug |
| Disk | 1-Sep |
| Plant Wheat | 15-Sep |

| Stubble Mulch (Grain Only) | |
|---|---|
| Operation | Date |
| 40 lb/acre Nitrogen (surface) | 1-Feb |
| Harvest | 1-Jul |
| Duckfoot cultivator | 15-Jul |
| 30 lb/acre Phosphorous (surface) | 1-Sep |
| 40 lb/acre Nitrogen (sub-surface) | 1-Sep |
| Disk | 1-Sep |
| Plant Wheat | 15-Sep |

# Calibration

Calibration is the process by which a model is adjusted to more closely match some observed data. Calibration greatly improves the accuracy of a model. The SWAT model was calibrated using observed stream flow. However, insufficient water quality data were available to perform any sediment or nutrient calibration.

### Calibration areas

Three USGS flow gages have daily data useful for calibration, Medicine Lodge near Kiowa, Salt fork near Alva and Salt Fork near Jay (Figure C1). The basin was divided into 3 areas:

1. Area above the Salt Fork near Alva gage, referred to as the Salt Fork calibration area.

2. Area above the Medicine Lodge near Kiowa gage, referred to as the Medicine Lodge calibration area.

3. Area above the Salt Fork near Jay gage but not included in previous two areas. Referred to as the GSP (Great Salt Plains) Reservoir area since the gage that serves this area is just below the reservoir dam.

Calibration using data from the Salt Fork near Jay gage is limited to average annual total flow, because baseflow separation cannot be performed on data collected downstream any significant catchment.

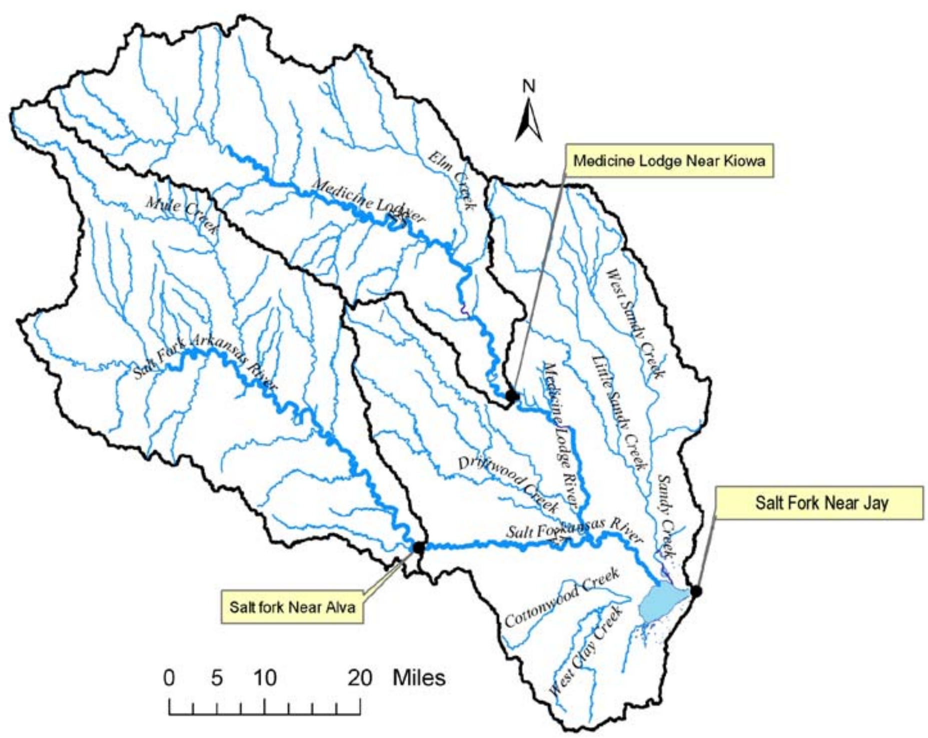


**Figure C1** River, streams, and active gage stations in the Great Salt Plains Basin.

## Baseflow Separation

Stream flow has two primary sources: surface runoff and ground water. Ground water contributions to stream flow is baseflow. The SWAT model was calibrated separately against observed surface and baseflow. Baseflow was separated from the total observed stream flow using the USGS HYSEP[5] sliding interval method. The method works as follows:

The duration of surface runoff is calculated from the empirical relationship:

$$N = A^{0.2}$$

Where N is the number of days after which surface runoff ceases and A is the drainage area in square miles. The interval 2N* used for hydrograph separations is the odd integer between 3 and 11 nearest to 2N. We adjusted the interval to provide a range of acceptable baseflow values. The sliding-interval method finds the lowest discharge in one half the interval minus 1 day [0.5(2N*-1) days] before and after the day being considered and assigns it to that day. The method can be visualized as moving a bar 2N* wide upward until it intersects the hydrograph. The discharge at that point is assigned to the median day in the interval. The bar then slides over to the next day, and the process is repeated (Figure C2).

Baseflow fractions were higher than expected throughout the basin. This could be the result of the shallow ground water and wetlands commonly found throughout the basin.

**Table C1** Observed average flow and baseflow fractions as determined by the HYSEP sliding interval method.

| Gage | Total Flow (m^3/sec) | Baseflow (m^3/sec) | | Surface Runoff (m^3/sec) | |
|---|---|---|---|---|---|
| | | High | Low | High | Low |
| Salt Fork | 3.96 | 57% | 51% | 49% | 43% |
| Medicine Lodge | 5.26 | 63% | 58% | 42% | 37% |

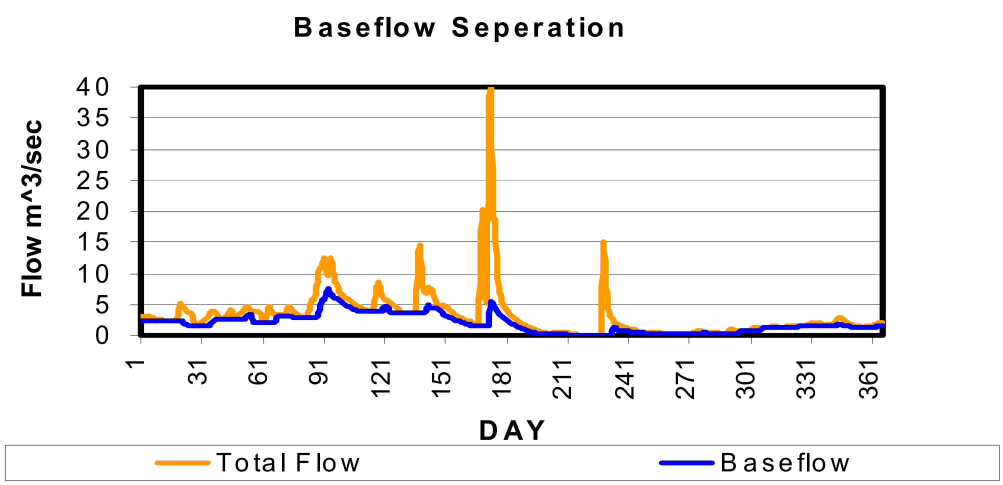


**Figure C2** Baseflow separation hydrograph example.

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[5] Sloto, R. A., Crouse, M. Y., HYSEP: "A Computer Program for Stream flow Hydrograph Separation and Analysis, U.S. Geological Survey

## Calibration Results

Table C2 contains observed and SWAT simulated flow after calibration. Average annual total flow at all three areas was calibrated to within 3% of the observed flow (Table C3). Larger errors are permissible for both surface runoff and baseflow fractions since the observed values are only estimates.

**Table C2** Observed and SWAT simulated flows for each calibration area.

| | Simulated | | | Observed | | |
|---|---|---|---|---|---|---|
| Area | Total flow | Surface runoff | Baseflow | Total flow | Surface runoff | Baseflow |
| Medicine Lodge Area | 5.40 | 2.93 | 2.47 | 5.27 | 3.16 | 2.11 |
| Salt Fork Area | 3.99 | 2.29 | 1.70 | 3.96 | 2.00 | 1.96 |
| Entire Basin | 13.17 | N/A | N/A | 13.34 | N/A | N/A |

**Table C3** Relative difference in flow from each calibration area. Relative difference calculated as (Observed-Predicted)/Observed * 100.

| Relative Difference | | | |
|---|---|---|---|
| Area | Total flow | Surface runoff | Baseflow |
| Medicine Lodge Area | -3% | 7% | -17% |
| Salt Fork Area | -1% | -15% | 13% |
| Entire Basin | 1% | N/A | N/A |

## Salt Fork Calibration

The Salt Fork calibration area is 982 square miles in area, and is represented by 55 subbasins and 465 HRUs in the SWAT model. Figures C3 and C4 contain the results of the calibration.

The following modifications to the default model were made to calibrate this area:

- Curve numbers were reduced by 4.
- Soil available water capacity was reduced by 0.005.
- Soil evaporation compensation factor was increased from 0.95 to 0.99.
- Initial depth of water in the shallow aquifer was increased to 100 mm.
- Depth of water in shallow aquifer required for baseflow was set to 100 mm.
- Depth of water in shallow aquifer required for revap was set to 300 mm.
- Recharge to the deep aquifer was set to 0.

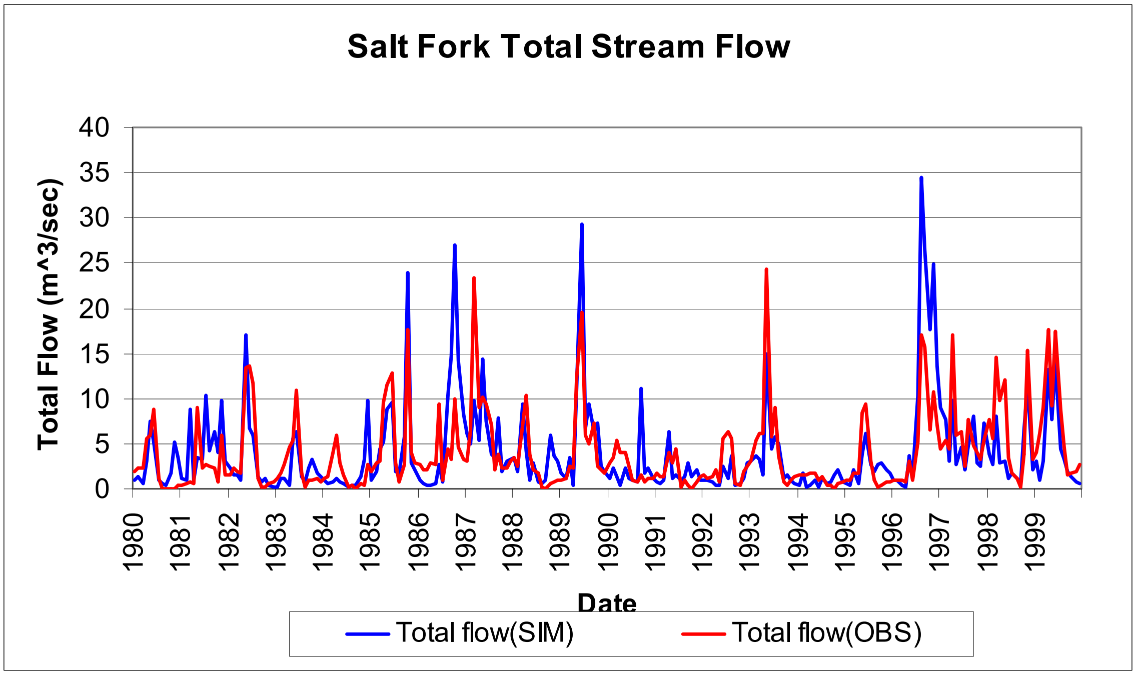



**Figure C3** SWAT simulated and observed total flow for the Salt Fork calibration area.

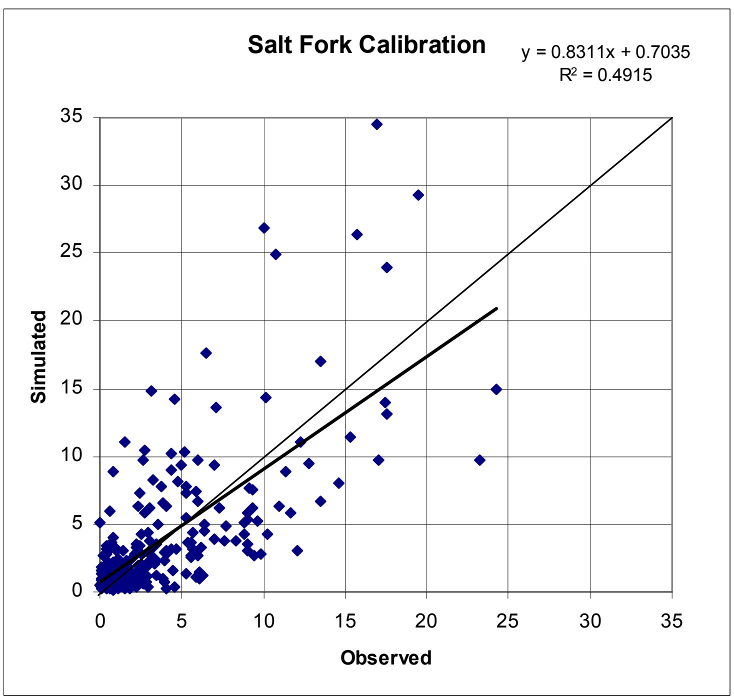



**Figure C4** SWAT simulated vs. observed total flow for the Salt Fork calibration area.

## Medicine Lodge Calibration

The Medicine Lodge calibration area is 889 square miles in area, and is represented by 69 subbasins and 855 HRUs in the SWAT model. Figure C5 and C6 contain additional detail about the results of the hydrologic calibration.

The following modifications to the default model were made to calibrate this area:

- Curve numbers were reduced by 4.
- Soil available water capacity was reduced by 0.027.
- Soil evaporation compensation factor was increased from 0.95 to 0.99.
- Initial depth of water in the shallow aquifer was increased to 100 mm.
- Depth of water in shallow aquifer required for baseflow was set to 100 mm.
- Depth of water in shallow aquifer required for revap was set to 300 mm.
- Recharge to the deep aquifer was set to 0.

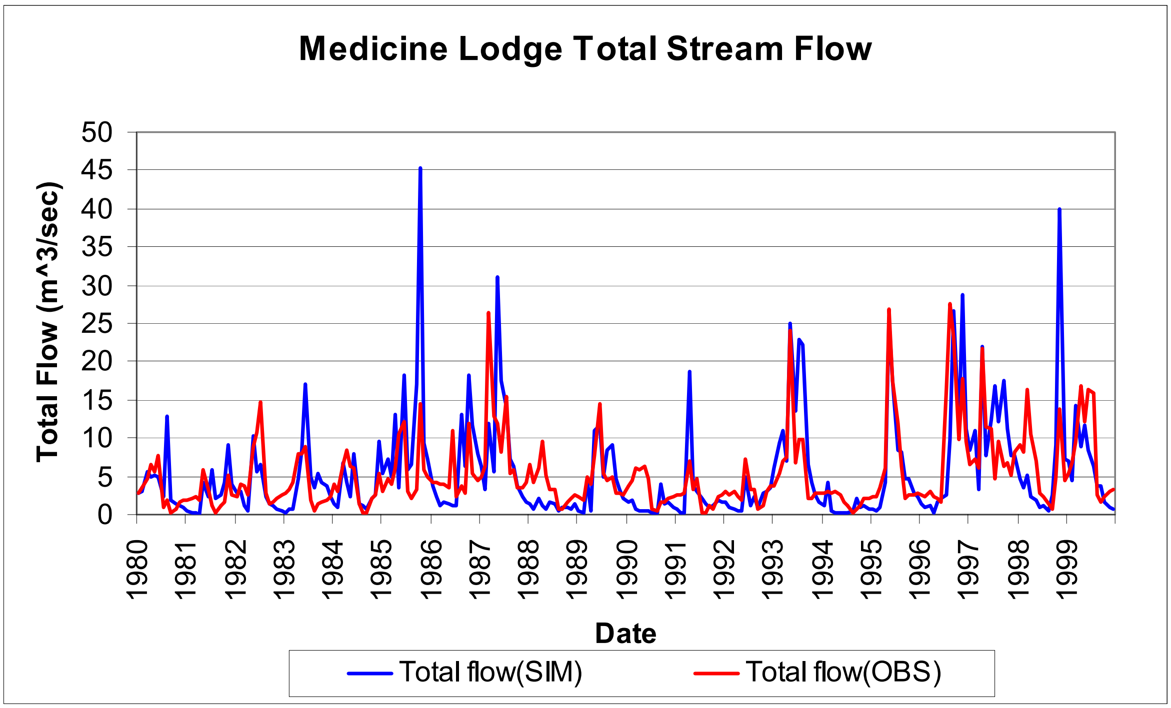



**Figure C5** SWAT simulated and observed total flow for the Medicine Lodge calibration area.

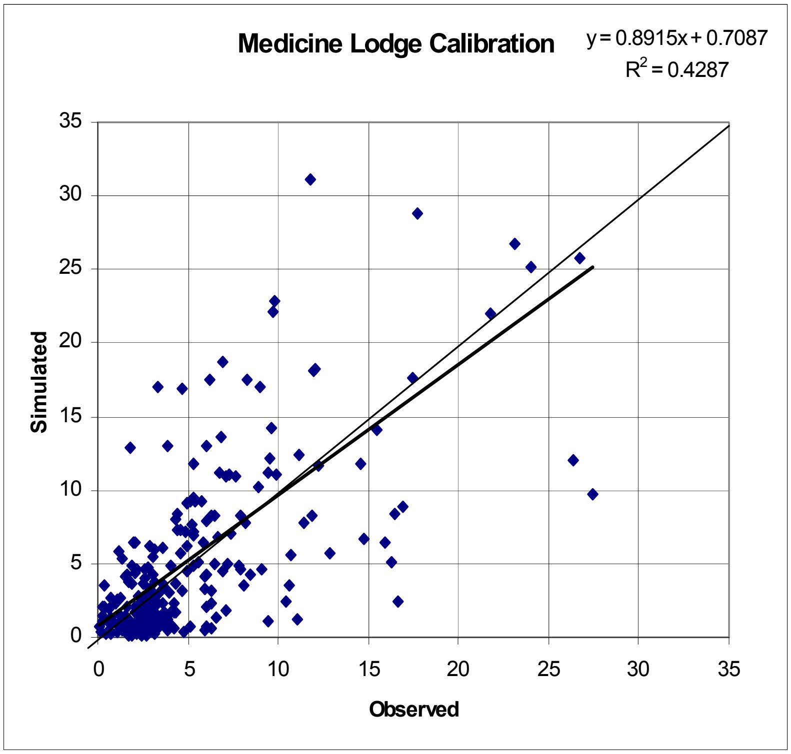



**Figure C6** SWAT simulated vs. observed total flow for the Medicine Lodge calibration area.

### GSP Calibration Area

The area downstream the gages was calibrated using stream gage data taken downstream the Great Salt Plains Reservoir dam. The period of record at this USGS station (Salt Fork Arkansas River Near Jet, OK) was shorter than the pervious stations, lasting only until 1993. Because this station is downstream the reservoir, baseflow separation is not possible. Only total flow on an average annual basis was calibrated at this station. Annual comparisons are available in Figure C7.

The following modification to the default model were made to calibrate this area:

- Curve numbers were reduced by 4.
- Soil available water capacity was reduced by 0.01.
- Soil evaporation compensation factor was reduced from 0.95 to 0.94.
- Initial depth of water in the shallow aquifer was increased to 100 mm.
- Depth of water in shallow aquifer required for baseflow was set to 100 mm.
- Depth of water in shallow aquifer required for revap was set to 300 mm.
- Recharge to the deep aquifer was set to 0.

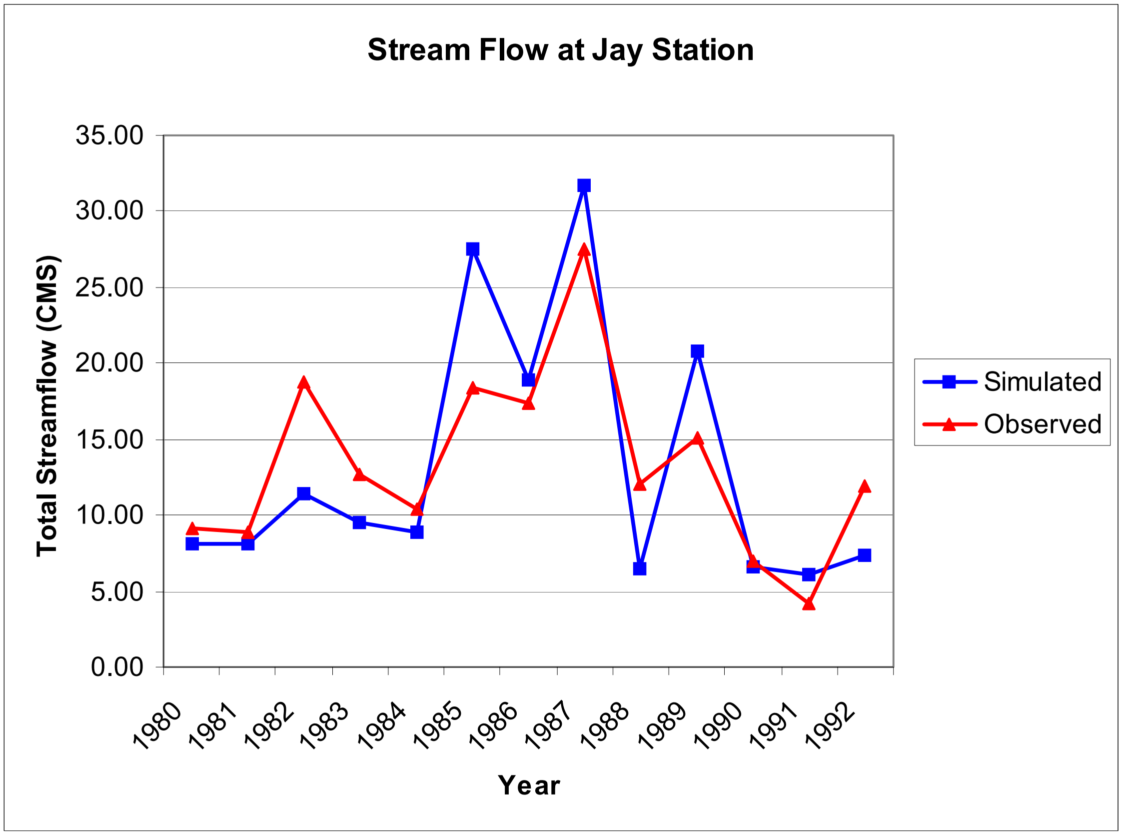



**Figure C7** Observed and SWAT predicted annual total flow at the Jay gage station.

## Spatial Characteristics of the Calibrated Model

Because SWAT is a distributed model, it is possible to view model output as it varies across the basin. Since there were no data with which to calibrate the nutrient, sediment and pesticide components of the model, all results were compared on a relative basis. Model calibration was performed stream flow that has been routed to the basin outlet. It is not possible to view these routed data on a per unit area basis in any meaningful manner. Figures depicting the spatial nature of model outputs use unrouted data only.

Figures D1 and D2 depict the variability of baseflow and surface runoff across the basin. North central Barber county was estimated to have a high average surface runoff, particularly for a rangeland area. This is thought to be the result of steep slopes and the increased occurrence soils with high runoff potential in this particular portion of the basin. Sediment yield (Figure D3) in the area was also elevated for a predominantly rangeland area; however, the wheat that is located in this area produced more sediment than average. Sediment yield for Alfalfa county was low considering the amount of wheat production in the area, possibly the result of the nearly flat topography of the area. Sediment-bound phosphorous is displayed in Figure D4. Soluble phosphorous yields (Figure D5) were highest in northern Barber and Alfalfa counties. Nitrate losses in surface runoff is displayed in Figure D6.

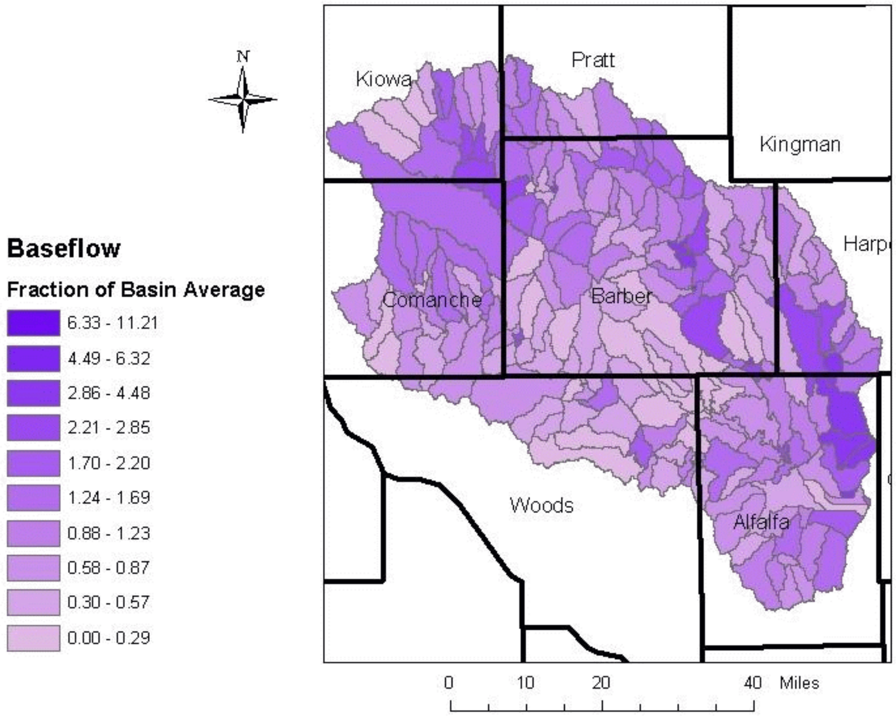



**Figure D1** Baseflow as a fraction of the basin average as simulated by SWAT for the Great Salt Plains Reservoir basin. Derived from a 20-year (1980-1999) simulation**.**

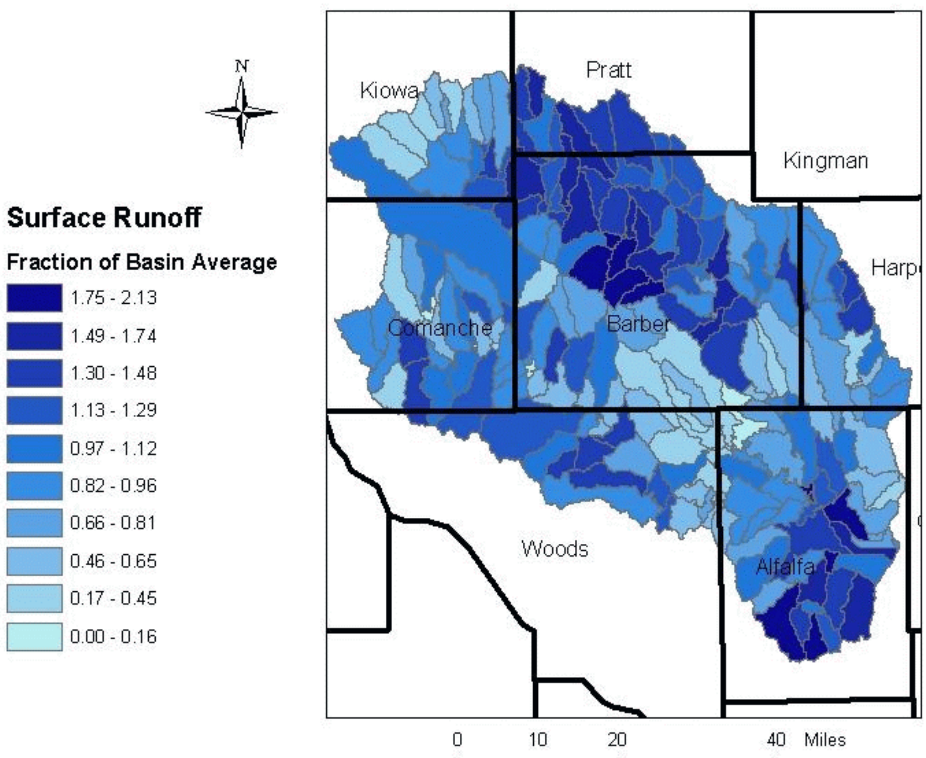



**Figure D2** Surface runoff as a fraction of the basin average as simulated by SWAT for the Great Salt Plains Reservoir basin. Derived from a 20-year (1980-1999) simulation**.**

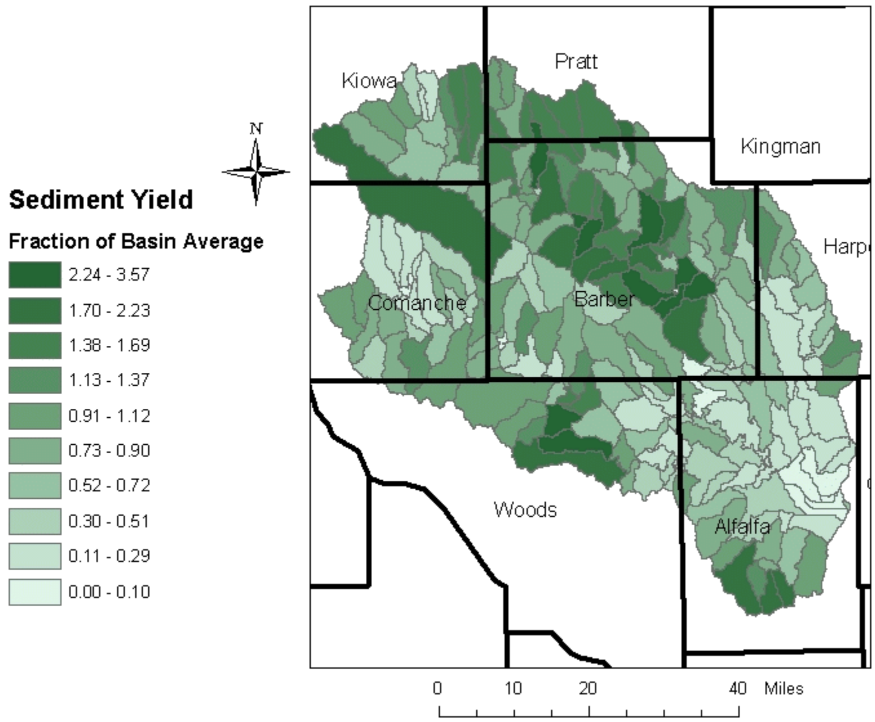



**Figure D3** Sediment Yield as a fraction of the basin average as simulated by SWAT for the Great Salt Plains Reservoir basin. Derived from a 20-year (1980-1999) simulation**.**

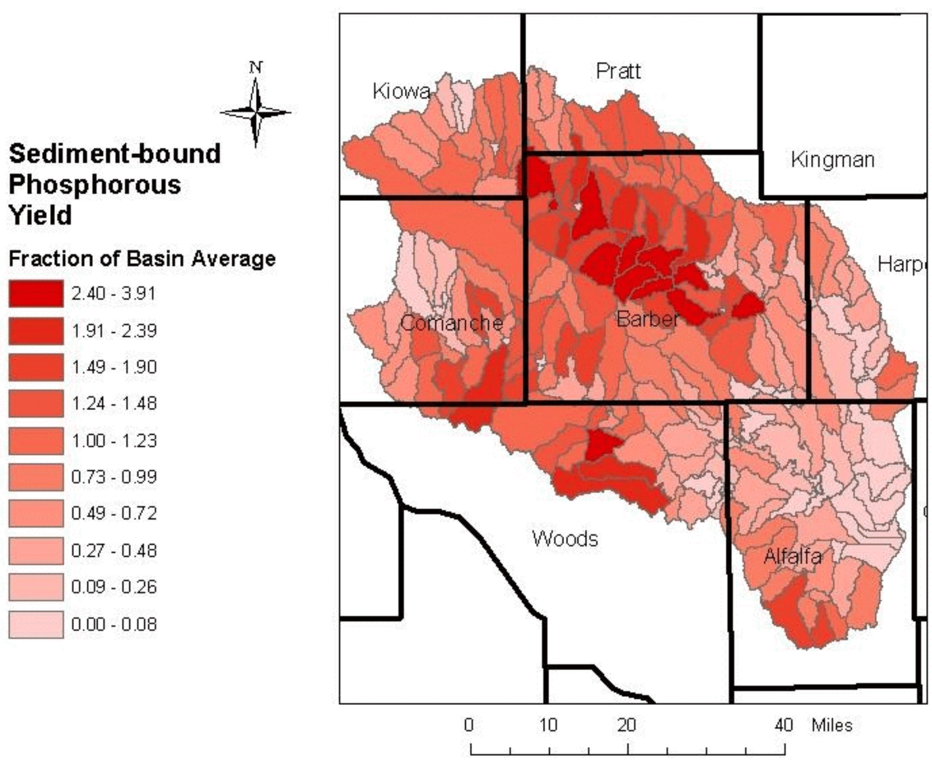



**Figure D4** Sediment-bound Phosphorous as a fraction of the basin average as simulated by SWAT for the Great Salt Plains Reservoir basin. Derived from a 20-year (1980-1999) simulation**.**

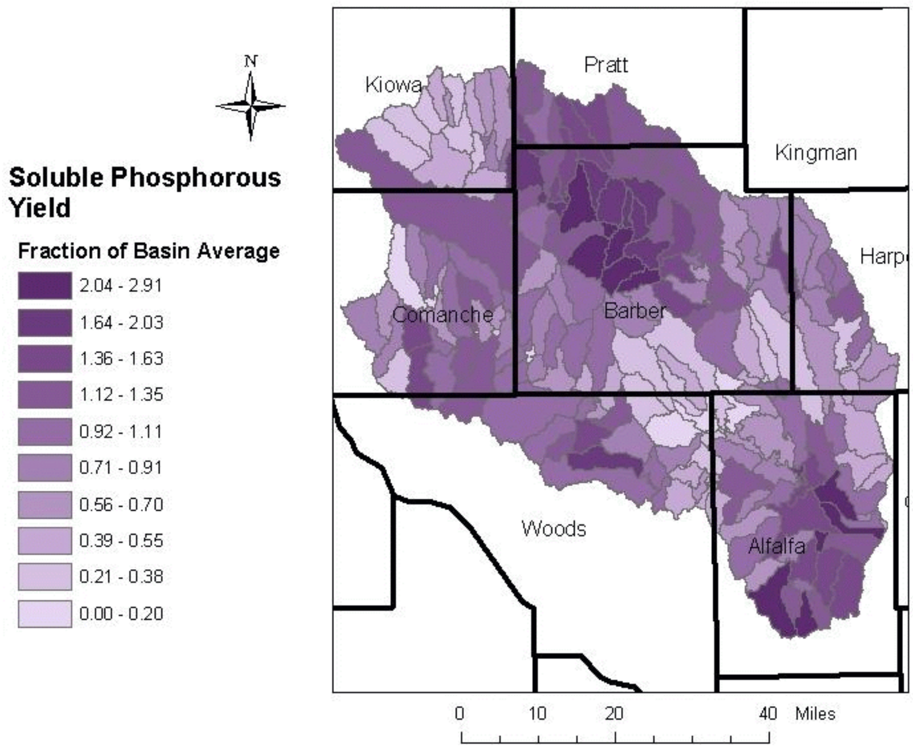



**Figure D5** Soluble phosphorous as a fraction of the basin average as simulated by SWAT for the Great Salt Plains Reservoir basin. Derived from a 20-year (1980-1999) simulation**.**

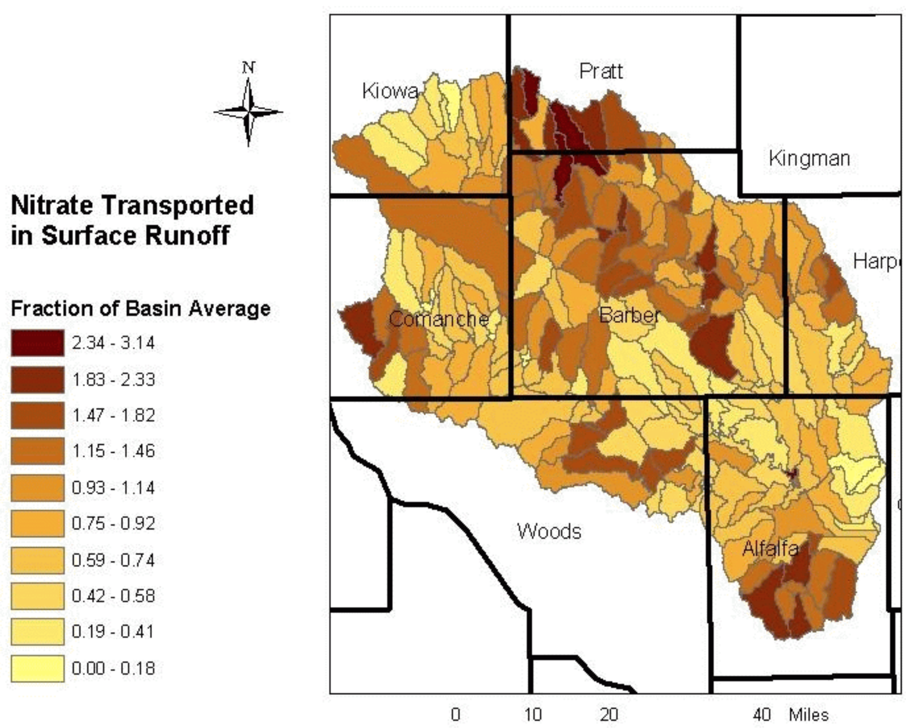



**Figure D6** Nitrate transported in surface water as a fraction of the basin average as simulated by SWAT for the Great Salt Plains Reservoir basin. Derived from a 20-year (1980-1999) simulation.

## Land Cover Comparisons

Each land cover represented in the model yielded different results. The differences are the result of not only its characteristics, but where that land cover tends to be located in the basin. A particular land cover is often found in conjunction with a particular soil type or topography.

Because SWAT summarizes land cover and soils into HRUs it was not possible to simulate exactly the same land cover fractions as depicted in the original land cover GIS data. Any land cover that covered less than 3% of a subbasin was ignored to reduce the computational requirement of the model. This effectively reduced the total area of small or scattered land covers represented in the model (Figure D7). Forest is an example of a land cover which was reduced in the model`s representation of the basin. Land covers such as range which cover a vast fraction of the basin tend to gain some area.

SWAT predicts quite different results for each type of land cover. Predictions by land cover are available in Figures E8 and E9. These are displayed as a fraction of the basin average on a per unit area basis for each parameter. The total contribution of each land cover type is dependant on its total coverage area. SWAT predicts agricultural areas have a higher sediment yield than rangeland on a per unit area basis.

The relative contribution of each land cover type and its area was used to determine how much of the total basin load it was responsible for (Table D1 and Figure D10). Wheat was responsible for 66% of the sediment and 92% of the leached nitrate. Range accounts for the majority of runoff and phosphorous.

**Table D1** Relative contribution of each land cover to the total basin load. Derived from 20 years of SWAT simulated data. Also shown in figure D10.

| Land Cover | Runoff | Baseflow | ET | Sediment | Sed-Bound P | Nitrate in Runoff | Soluble P | Nitrate Leached | Organic N |
|---|---|---|---|---|---|---|---|---|---|
| Wheat | 38.4% | 32.6% | 27.6% | 66.5% | 44.4% | 53.1% | 31.6% | 92.5% | 92.5% |
| Range | 52.3% | 59.1% | 64.9% | 25.0% | 52.0% | 42.2% | 58.4% | 3.4% | 3.4% |
| Soybean | 4.5% | 3.4% | 2.4% | 7.8% | 2.7% | 2.4% | 0.9% | 0.4% | 0.4% |
| Alfalfa | 0.8% | 3.3% | 1.4% | 0.5% | 0.9% | 0.3% | 3.1% | 3.4% | 3.4% |
| Forest | 0.0% | 0.1% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Water | 0.0% | 0.0% | 1.4% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Urban | 0.2% | 0.1% | 0.2% | 0.2% | 0.1% | 0.1% | 0.1% | 0.2% | 0.2% |
| Wetlands | 3.8% | 1.4% | 2.1% | 0.0% | 0.0% | 2.0% | 5.8% | 0.1% | 0.1% |

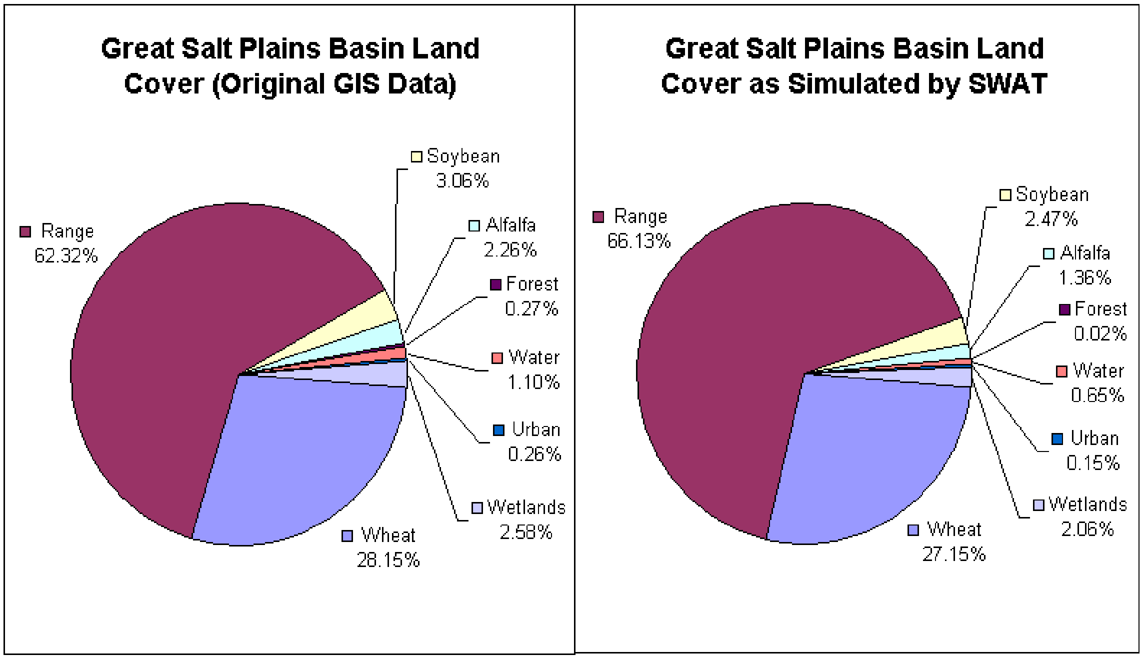



**Figure D7** Land cover fractions of the original GIS data, and that used in all SWAT simulations.

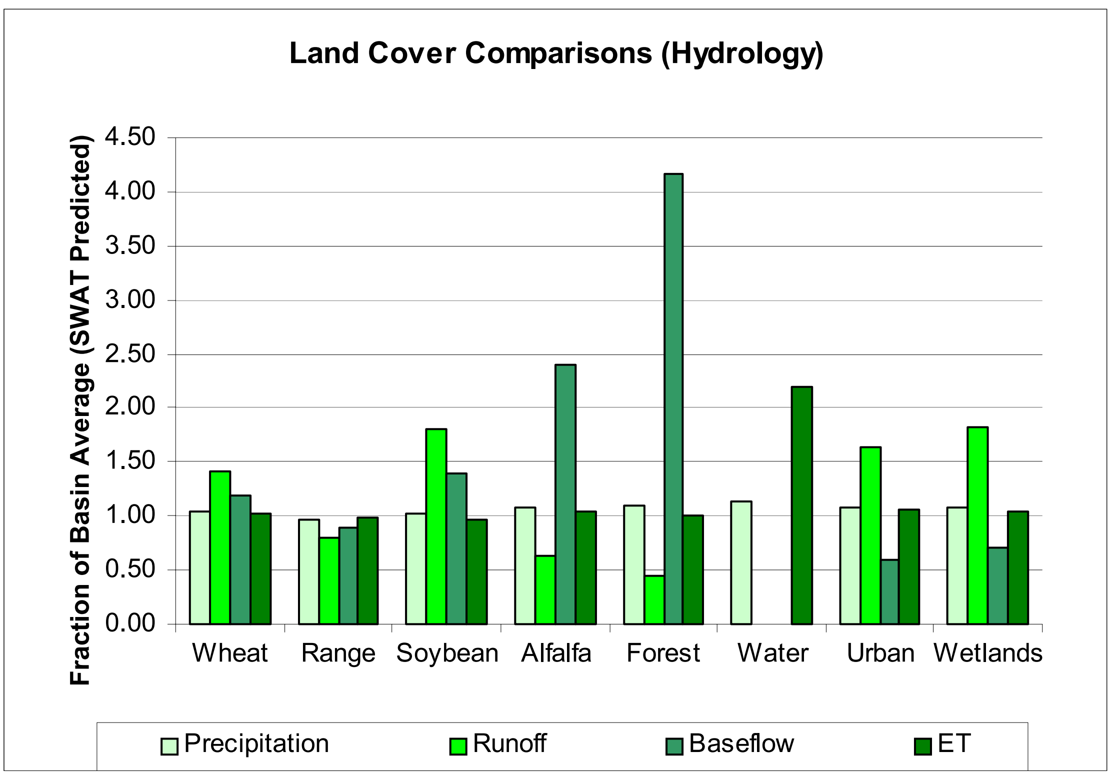



**Figure D8** SWAT predicted land cover hydrological comparisons. Derived from a 20-year of simulation of the calibrated model.

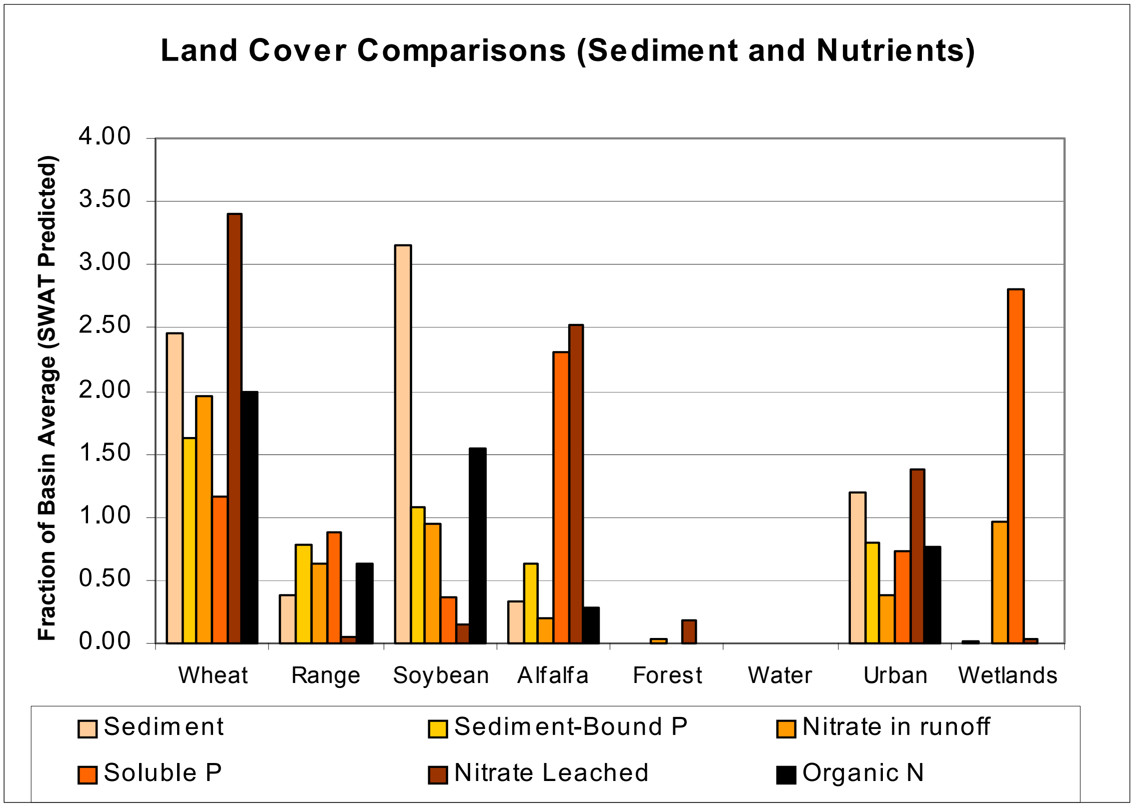



**Figure D9** SWAT predicted land cover sediment and nutrient comparisons. Derived from a 20-year of simulation of the calibrated model.

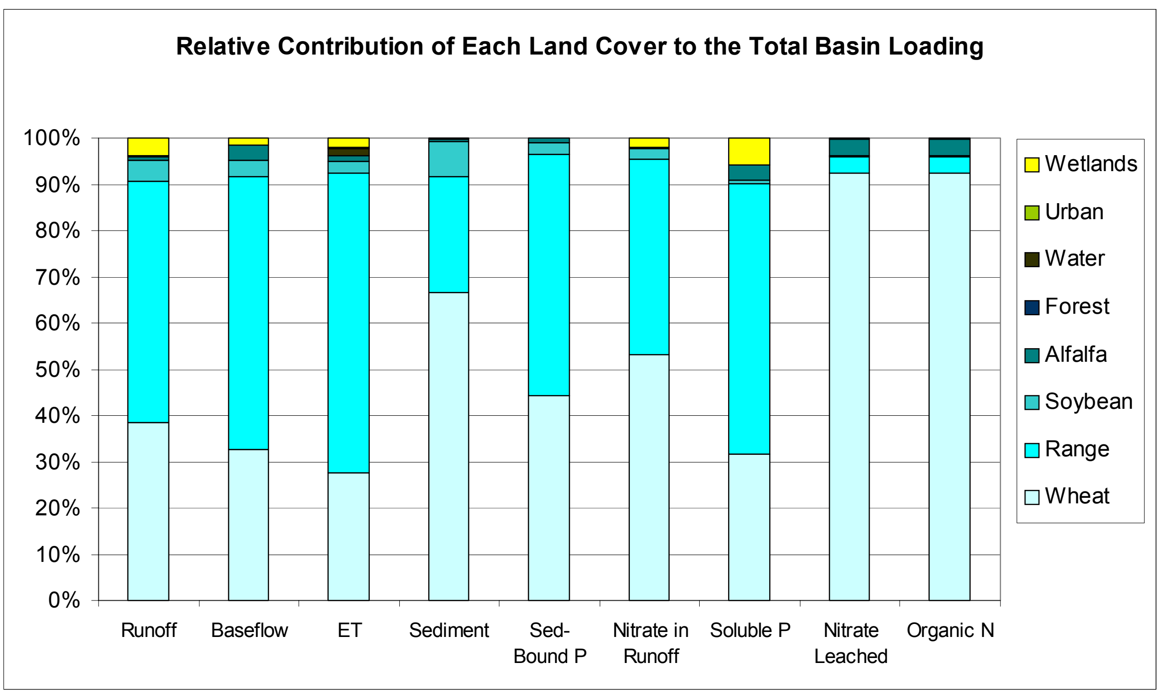



**Figure D10** Relative contribution of each land cover to the total basin load. Derived from a 20-year of simulation of the calibrated model.

## Temporal Nature of Model Outputs by Land Cover Type

Water and nutrient yields variety with time. Weather and land cover conditions influence these yields, thus they vary from month to month. Summarizing monthly simulation data gives additional insight about when nutrient or water yields are likely to be the greatest.

The effect of summer tillage on wheat is evident in Figure D11. Sediment yields are dramatically increased while the land is fallow. An increase in surface runoff is also apparent during this period even though there is no significant increase in precipitation. Figure D12 indicates increased sediment-bound nutrient yields for this time frame. Rangeland is not subject to tillage and retains a more uniform soil cover through the seasons. Figure D13 illustrates a much more consistent relationship between surface runoff and sediment yields. Rangeland nutrient yields are available in Figure D14. Alfalfa (Figures D15 and D16) exhibits an unusual sediment spike in the spring, possibly due to slow simulated growth and the lack of surface residue from hay cuttings the previous year.

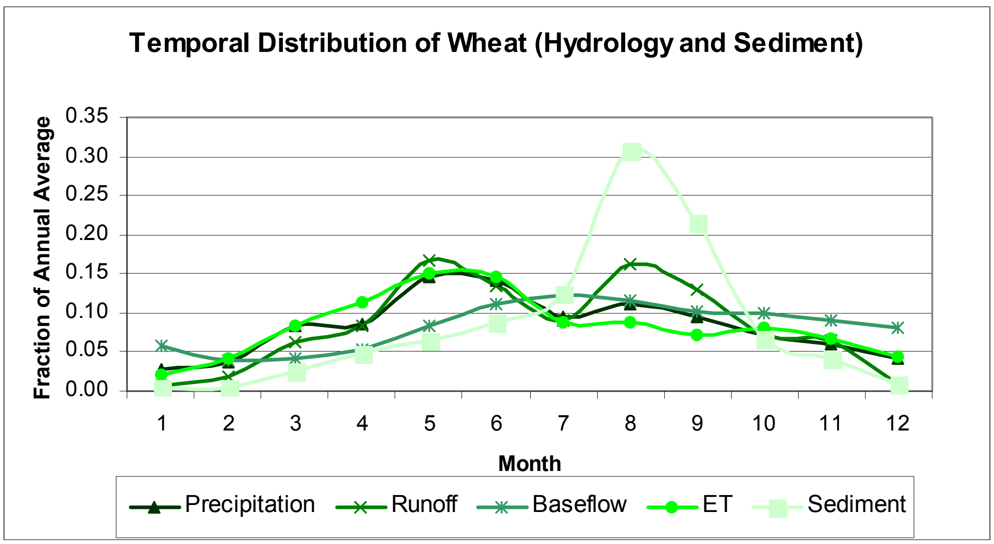



**Figure D11** Hydrologic and sediment temporal characteristics of wheat as simulated by SWAT. Fraction of average annual yield occurring any given month taken from 20 years of simulated data.

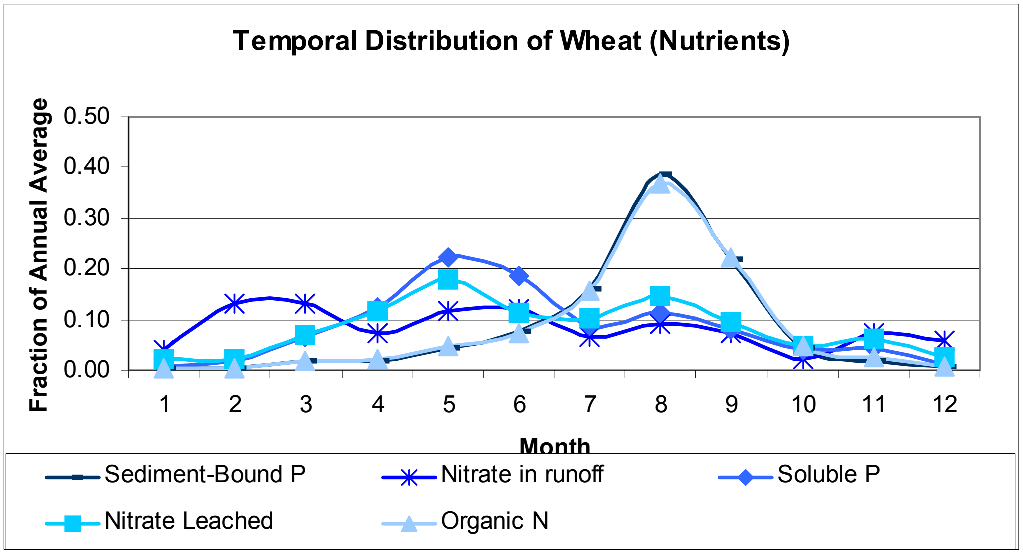



**Figure D12** Nutrient temporal characteristics of wheat as simulated by SWAT. Fraction of average annual yield occurring any given month taken from 20 years of simulated data.

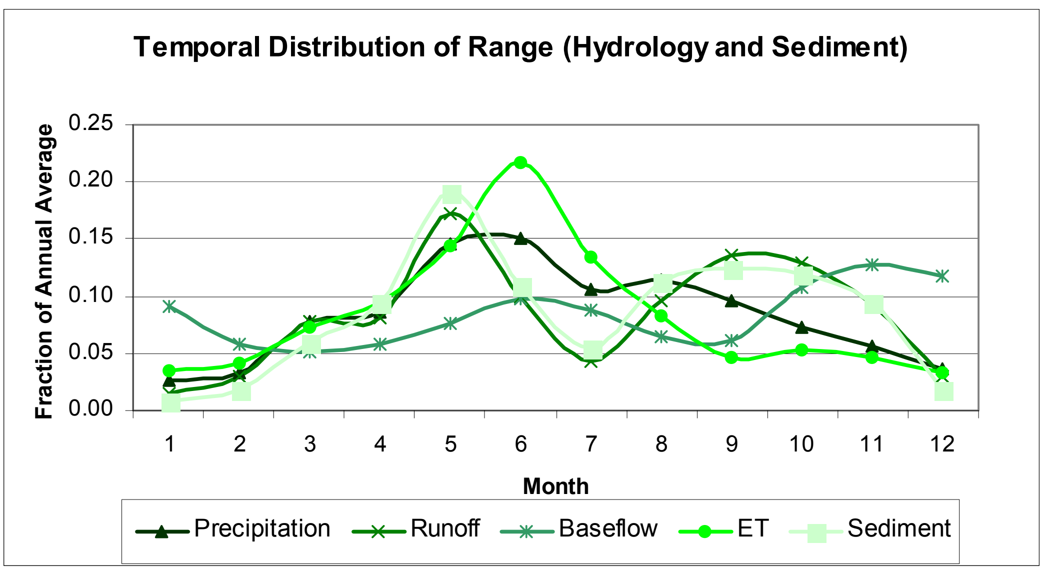



**Figure D13** Hydrologic and sediment temporal characteristics of range as simulated by SWAT. Fraction of average annual yield occurring any given month taken from 20 years of simulated data.

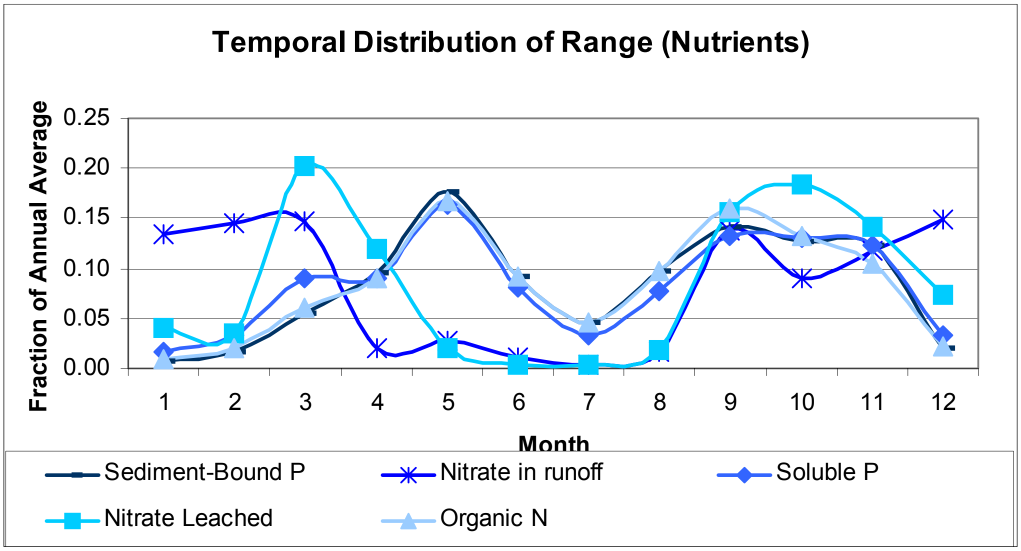



**Figure D14** Nutrient temporal characteristics of range as simulated by SWAT. Fraction of average annual yield occurring any given month taken from 20 years of simulated data.

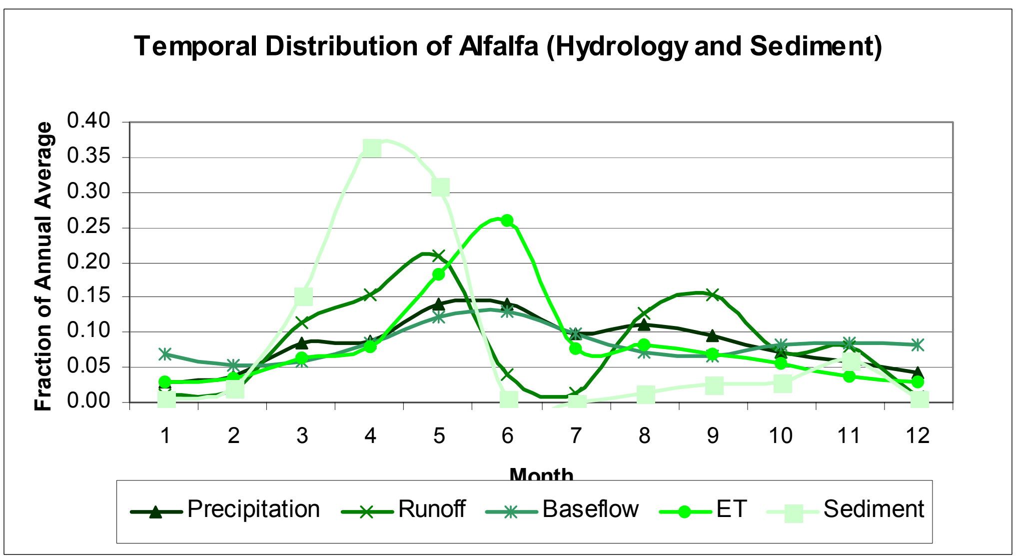



**Figure D15** Hydrologic and sediment temporal characteristics of Alfalfa as simulated by SWAT. Fraction of average annual yield occurring any given month taken from 20 years of simulated data.

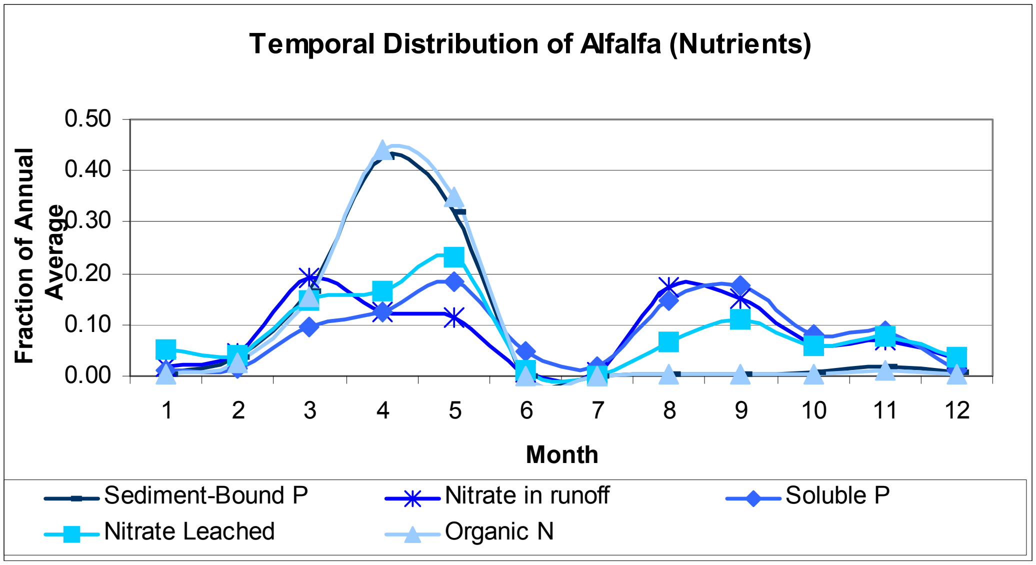



**Figure D16** Nutrient temporal characteristics of Alfalfa as simulated by SWAT. Fraction of average annual yield occurring any given month taken from 20 years of simulated data.

## Best Management Practices

The calibrated SWAT model was modified to simulate a variety of BMPs. These BMPs were selected to represent commonly occurring and recommended practices for wheat and alfalfa in Oklahoma. In addition, the selected BMPs must be suitable for modeling; some field scale BMPs such as filter strips are beyond the abilities of current basin scale models such as SWAT. Rates and operation timings were selected to represent reasonable values for the basin.

Statistical analyses were performed using SAS (Statistical Analysis Software). SAS programs used to perform the analysis are available in the appendix. Each comparison was made using model output for the period Jan. 1,1980 to Dec. 31,1999. Year was blocked to remove the overwhelming error associated with year to year variation.

The following BMPs were examined using SWAT:

- Tillage and harvest type BMPs
    - Tillage type on wheat.
    - Harvest type on wheat.
- Fertilization BMPs
    - Nitrogen fertilizer timing on wheat.
    - Nitrogen fertilizer application rate on wheat.
    - Phosphorous fertilization rate on wheat.
- Pesticide BMPs
    - Herbicide application timing on wheat.
    - Insecticide application on alfalfa.

## Tillage and Harvest Type BMPs

Tillage and harvest type were arranged in a 3x3 factorial experimental design. Each level of tillage was compared at each harvest type and vise versa. Tables E1 and E2 contain mean and standard deviations on a relative basis for each of the nine simulations. Management operation are listed in Tables E3 and E4 for each land cover and potential BMP.

### Tillage BMPs

Tillage is required to control weeds and to prepare a suitable seedbed for planting. Many different implements can be used. SWAT simulates tillage by mixing the soil layers and incorporating residue from the soil surface. The degree of soil disturbance is more important than the actual implement used.

Three common types of tillage were selected as BMPs:

1. Moldboard Plow

2. Stubble Mulch

3. Low Till

Each type of tillage represents a different level of soil disturbance, with moldboard plow being the most disturbing and low till the least. Low till operations use herbicides to a greater extent to control weeds. Each tillage was simulated at three different cattle grazing scenarios. Tillage had a significant effect on sediment yield and sediment-bound nutrients (Figure E1). Figure E2 contains variations in tillage at a constant harvest type. Figure E3 presents a direct comparison of means for all levels of tillage and harvest type.

### Harvest Type BMPs

Wheat is often used as a winter forage in Oklahoma before it is harvested for grain in the summer. Depending on market conditions wheat may be grazed out or harvested for hay and not harvested for grain at all. These three grazing scenarios were simulated using SWAT:

1. No grazing, harvested for grain only.

2. Cattle grazing and harvested for grain.

3. Grazing only, harvested for hay.

Fertilization rates and planting timing are adjusted for each scenario. Wheat grazing was simulated at approximately 0.33 animal units per acre (Oklahoma State University Extension Facts 2855) for a maximum of 100 days. Additional fertilization is based on stocking rate when also harvested for grain. An additional 30 lb/acre nitrogen is applied to compensate for nitrogen removal by cattle (Oklahoma State University Extension Facts F-2586). Any time there is less than 600 kg (dry weight) of biomass per hectare, grazing is suspended.

**Table E1** Relative means of harvest and tillage BMP simulations. Derived from 20 years of simulated data.

| Tillage | Grazing | Runoff | Baseflow | ET | Sediment | Sediment-bound P | Nitrate in runoff | Soluble P | Nitrate leached | Organic N | Lateral N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Moldboard | Grain Only | 0.98 | 0.97 | 1.00 | 1.07 | 0.99 | 0.93 | 0.87 | 0.66 | 1.06 | 0.82 |
| Stubble Mulch | Grain Only | 0.98 | 0.98 | 1.00 | 0.83 | 0.92 | 0.94 | 1.06 | 0.66 | 0.88 | 0.82 |
| Low Till | Grain Only | 0.98 | 0.98 | 1.00 | 0.69 | 0.99 | 0.96 | 1.54 | 0.65 | 0.81 | 0.82 |
| Moldboard | Grain and Grazing | 1.02 | 1.01 | 1.00 | 1.37 | 1.12 | 1.11 | 0.90 | 1.38 | 1.22 | 1.29 |
| Stubble Mulch | Grain and Grazing | 1.02 | 1.01 | 1.00 | 1.16 | 1.08 | 1.13 | 1.16 | 1.38 | 1.06 | 1.29 |
| Low Till | Grain and Grazing | 0.99 | 0.97 | 1.00 | 0.73 | 0.89 | 0.99 | 1.27 | 1.43 | 0.78 | 1.26 |
| Moldboard | Grazing | 0.69 | 0.50 | 1.05 | 0.91 | 0.90 | 0.70 | 0.52 | 0.56 | 0.96 | 1.10 |
| Stubble Mulch | Grazing | 0.69 | 0.51 | 1.05 | 0.50 | 0.51 | 0.76 | 0.79 | 0.59 | 0.50 | 1.15 |
| Low Till | Grazing | 0.70 | 0.52 | 1.05 | 0.41 | 0.74 | 0.84 | 1.75 | 0.58 | 0.52 | 1.16 |

**Table E2** Relative standard deviation of harvest and tillage BMP simulations. derived from 20 years of simulated data.

| Tillage | Harvest Type | Runoff | Baseflow | ET | Sediment | Sediment-bound P | Nitrate in runoff | Soluble P | Nitrate leached | Organic N | Lateral N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Moldboard | Grain Only | 0.88 | 1.15 | 0.07 | 1.32 | 1.29 | 0.78 | 1.01 | 0.92 | 1.37 | 0.57 |
| Stubble Mulch | Grain Only | 0.88 | 1.15 | 0.07 | 1.04 | 1.17 | 0.79 | 1.16 | 0.92 | 1.14 | 0.57 |
| Low Till | Grain Only | 0.88 | 1.15 | 0.07 | 0.89 | 1.28 | 0.80 | 1.54 | 0.90 | 1.07 | 0.57 |
| Moldboard | Grain and Grazing | 0.85 | 1.10 | 0.15 | 1.38 | 1.18 | 0.86 | 1.04 | 1.71 | 1.25 | 0.97 |
| Stubble Mulch | Grain and Grazing | 0.85 | 1.11 | 0.15 | 1.20 | 1.12 | 0.88 | 1.23 | 1.71 | 1.06 | 0.97 |
| Low Till | Grain and Grazing | 0.86 | 1.12 | 0.07 | 0.92 | 1.13 | 0.67 | 1.17 | 1.88 | 1.00 | 0.98 |
| Moldboard | Grazing | 0.54 | 0.59 | 0.15 | 0.74 | 0.67 | 0.54 | 0.54 | 0.91 | 0.72 | 0.44 |
| Stubble Mulch | Grazing | 0.54 | 0.59 | 0.15 | 0.67 | 0.63 | 0.60 | 0.73 | 0.94 | 0.64 | 0.46 |
| Low Till | Grazing | 0.54 | 0.60 | 0.15 | 0.61 | 1.10 | 0.68 | 1.46 | 0.93 | 0.78 | 0.45 |

**Table E3** Management operations for tillage and harvest type simulations for wheat.

| Tillage | Moldboard Plow | | Stubble Mulch | | Low Till | |
|---|---|---|---|---|---|---|
| Harvest | Operation | Date | Operation | Date | Operation | Date |
| Grain Only | 40 lb/acre Nitrogen (surface) | 1-Feb | 40 lb/acre Nitrogen (surface) | 1-Feb | 40 lb Nitrogen (surface) | 1-Feb |
| | Harvest | 1-Jul | Harvest | 1-Jul | Harvest | 1-Jul |
| | Moldboard plow | 15-Jul | Duckfoot cultivator | 15-Jul | 30 lb/acre Phosphorous (surface) | 1-Sep |
| | 30 lb/acre Phosphorous (surface) | 10-Aug | 30 lb/acre Phosphorous (surface) | 1-Sep | Chisle plow | 1-Sep |
| | Disk | 11-Aug | 40 lb/acre Nitrogen (sub-surface) | 1-Sep | 40 lb/acre Nitrogen (sub-surface) | 1-Sep |
| | 40 lb/acre Nitrogen (sub-surface) | 11-Aug | Disk | 1-Sep | Plant Wheat | 15-Sep |
| | Disk | 1-Sep | Plant Wheat | 15-Sep | | |
| | Plant Wheat | 15-Sep | | | | |
| Grain and Grazing | 70 lb/acre Nitrogen (surface) | 1-Feb | 70 lb/acre Nitrogen (surface) | 1-Feb | 70 lb/acre Nitrogen (surface) | 1-Feb |
| | Harvest | 15-Jun | Harvest | 15-Jun | Harvest | 1-Jul |
| | Moldboard plow | 15-Jul | Duckfoot cultivator | 15-Jul | 30 lb/acre Phosphorous (surface) | 1-Sep |
| | 30 lb/acre Phosphorous (surface) | 1-Aug | 30 lb/acre Phosphorous (surface) | 1-Aug | Chisle plow | 1-Sep |
| | Disk | 2-Aug | 40 lb/acre Nitrogen (sub-surface) | 15-Aug | 40 lb/acre Nitrogen (sub-surface) | 1-Sep |
| | 40 lb/acre Nitrogen (sub-surface) | 3-Aug | Disk | 30-Aug | Plant Wheat | 15-Sep |
| | Disk | 20-Aug | Plant Wheat | 1-Sep | Grazing .33 Animal unit/acre | 1-Nov |
| | Plant Wheat | 1-Sep | Grazing .33 Animal unit/acre | 1-Nov | | |
| | Grazing .33 Animal unit/acre | 1-Nov | | | | |
| Grazing and Hay | Harvest Hay | 15-Apr | Harvest Hay | 15-Apr | Harvest Hay | 15-Apr |
| | Kill Crop | 16-Apr | Kill Crop | 16-Apr | Kill Crop | 16-Apr |
| | Moldboard Plow | 15-Jul | 30 lb/acre Phosphorous (surface) | 15-Jul | 30 lb/acre Phosphorous (surface) | 15-Jul |
| | 30 lb/acre Phosphorous (surface) | 1-Aug | Duckfoot cultivator | 15-Jul | Chisle plow | 15-Jul |
| | Disk | 2-Aug | 80 lb Nitrogen (subsurface) | 15-Jul | 80 lb Nitrogen (subsurface) | 15-Jul |
| | 80 lb/acre Nitrogen (sub-surface) | 3-Aug | Disk | 5-Aug | Plant Wheat | 15-Aug |
| | Disk | 5-Aug | Plant Wheat | 15-Aug | Grazing .33 Animal unit/acre | 1-Nov |
| | Plant Wheat | 15-Aug | Grazing .33 Animal unit/acre | 1-Nov | | |
| | Grazing .33 Animal unit/acre | 1-Nov | | | | |

**Table E4** Management operations for land covers other than wheat.

| Alfalfa | | |
|---|---|---|
| Description | YEAR | Heat Unit Fraction |
| plant | 1 | 0.150 |
| 30 lb/acre Phosphorous (surface) | 1 | 0.300 |
| Harvest Hay | 1 | 0.400 |
| Harvest Hay | 1 | 0.800 |
| Harvest Hay | 1 | 1.200 |
| 30 lb/acre Phosphorous (surface) | 2 | 0.300 |
| Harvest Hay | 2 | 0.400 |
| Harvest Hay | 2 | 0.800 |
| Harvest Hay | 2 | 1.200 |
| 30 lb/acre Phosphorous (surface) | 3 | 0.300 |
| Harvest Hay | 3 | 0.400 |
| Harvest Hay | 3 | 0.800 |
| Harvest Hay | 3 | 1.200 |
| 30 lb/acre Phosphorous (surface) | 4 | 0.300 |
| Harvest Hay | 4 | 0.400 |
| Harvest Hay | 4 | 0.800 |
| Harvest/kill | 4 | 1.200 |

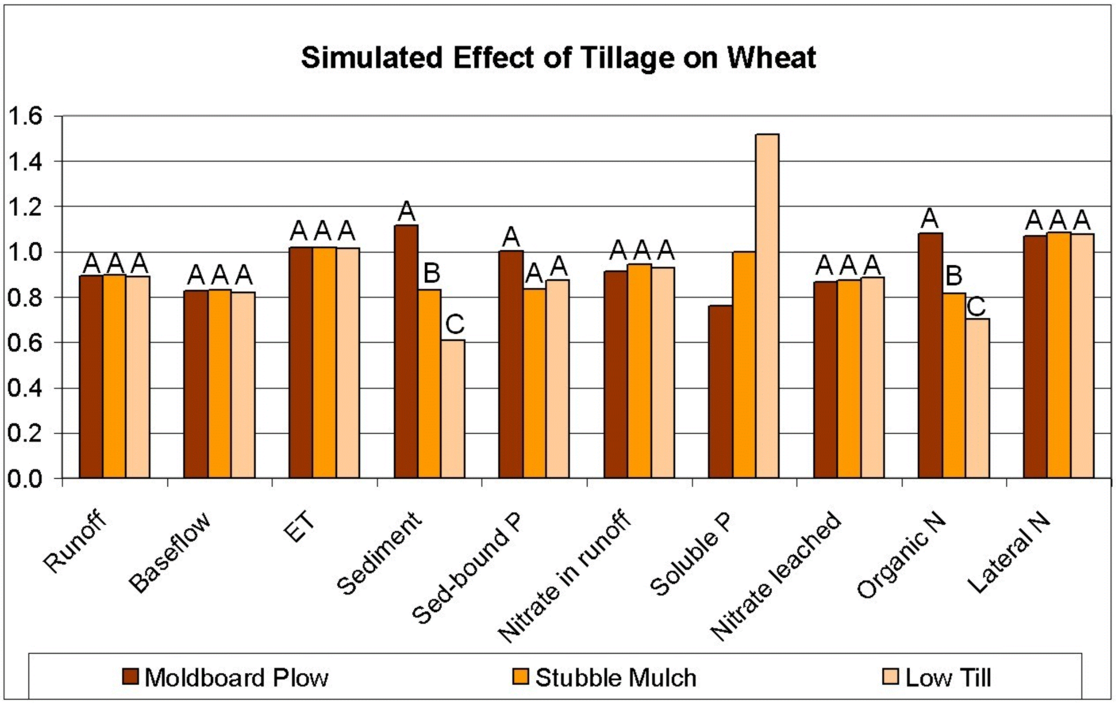
| Urban | | |
|---|---|---|
| Description | YEAR | Heat Unit Fraction |
| Plant | 1 | 0.150 |
| Harvest/Kill | 1 | 1.200 |

| Wetland | | |
|---|---|---|
| Description | YEAR | Heat Unit Fraction |
| Plant | 1 | 0.150 |
| Harvest/Kill | 1 | 1.200 |

| Range | | |
|---|---|---|
| Description | YEAR | Heat Unit Fraction |
| Plant | 1 | 0.150 |
| Harvest/Kill | 1 | 1.200 |

| Soybeans | | |
|---|---|---|
| Description | YEAR | Heat Unit Fraction |
| 30 lb Phosphorous | 1 | 0.03 |
| 80 lb Nitrogen | 1 | 0.03 |
| Disk | 1 | 0.04 |
| Plant | 1 | 0.25 |
| Harvest/kill | 1 | 1.20 |

| Forest | | |
|---|---|---|
| Description | YEAR | Heat Unit Fraction |
| Plant | 1 | 0.150 |
| Harvest/Kill | 1 | 1.200 |



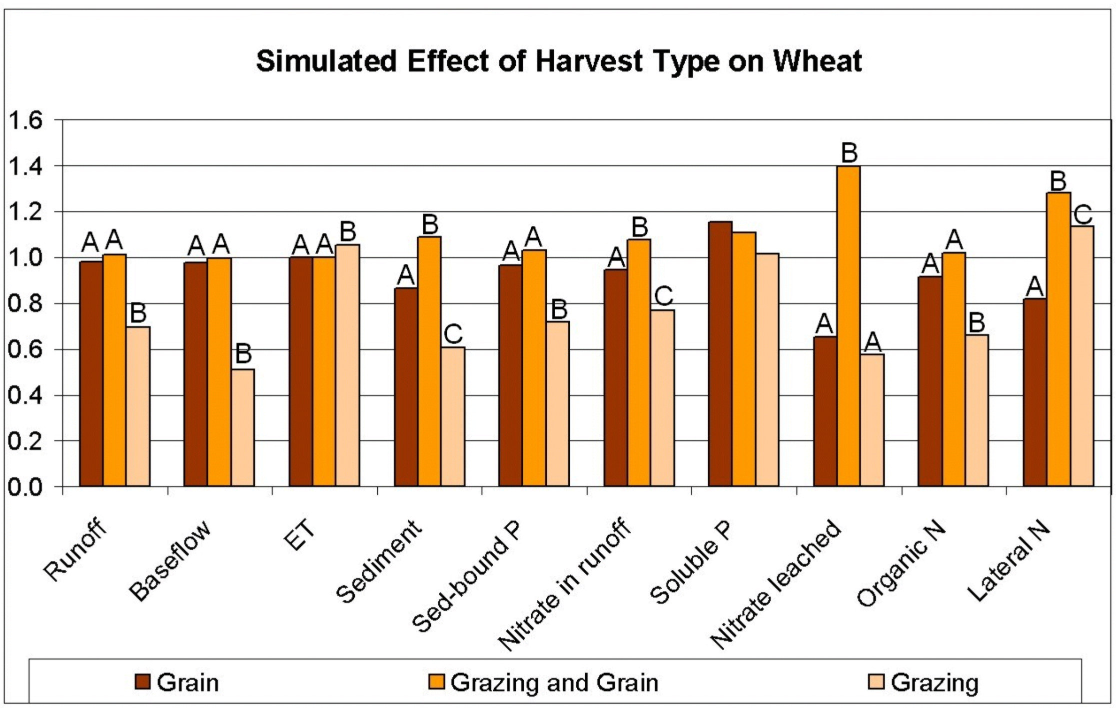




**Figure E1** Main effects of tillage (moldboard, stubble, and low till) and harvest type (grain only, grazing and grain, and grazing and hay).Displayed as a fraction of calibrated wheat average. Main effect statistical comparisons are not appropriate for soluble phosphorous due to interaction. Derived from 20-year SWAT simulations.

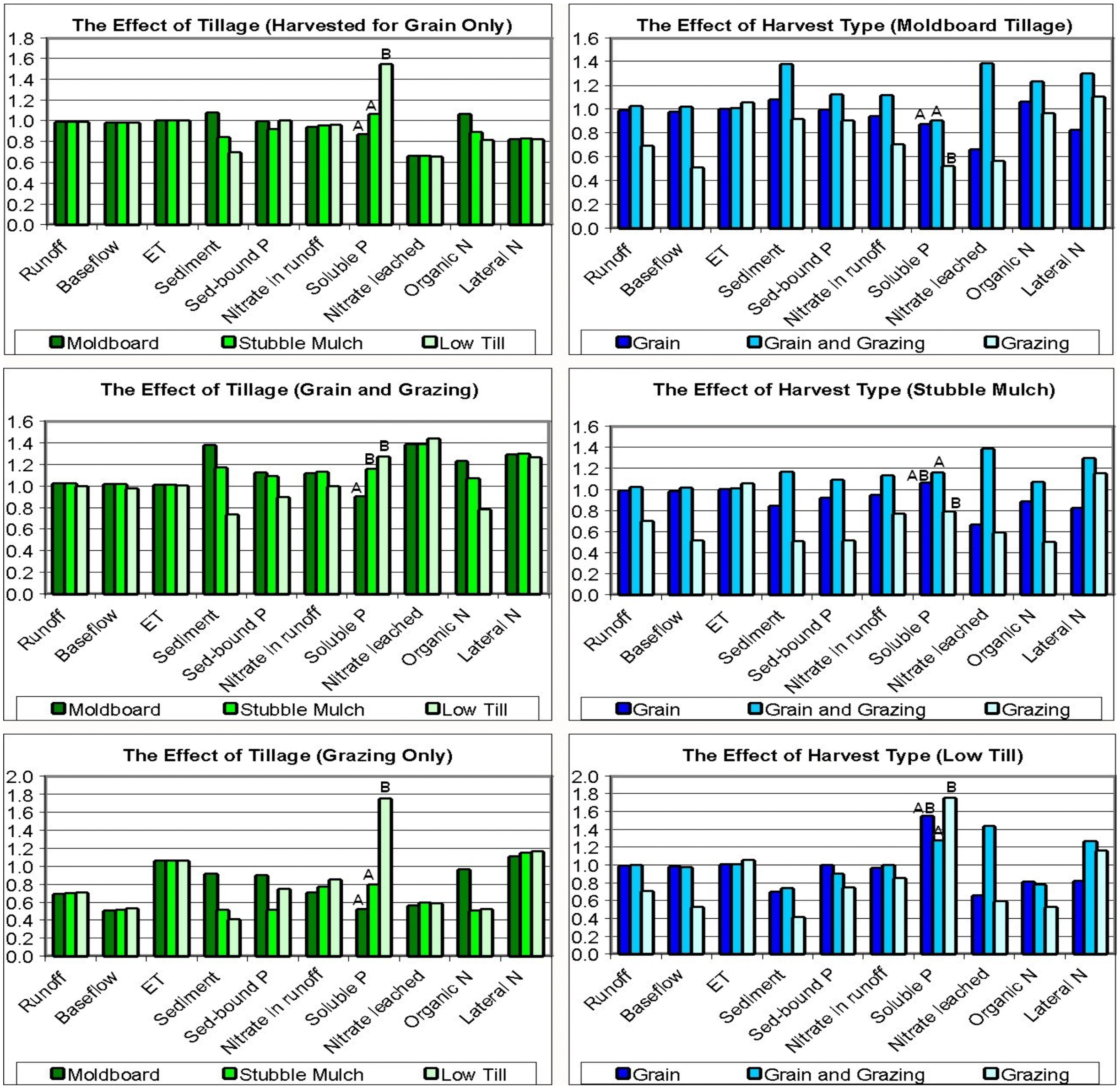



**Figure E2** Tillage effects at constant harvest type (grain, grazing, or both) and harvest type effects at constant tillage (moldboard, stubble, or low till). Displayed as a fraction of calibrated wheat average. Statistics generated for soluble phosphorous due to interaction. Derived from 20-year SWAT simulations.

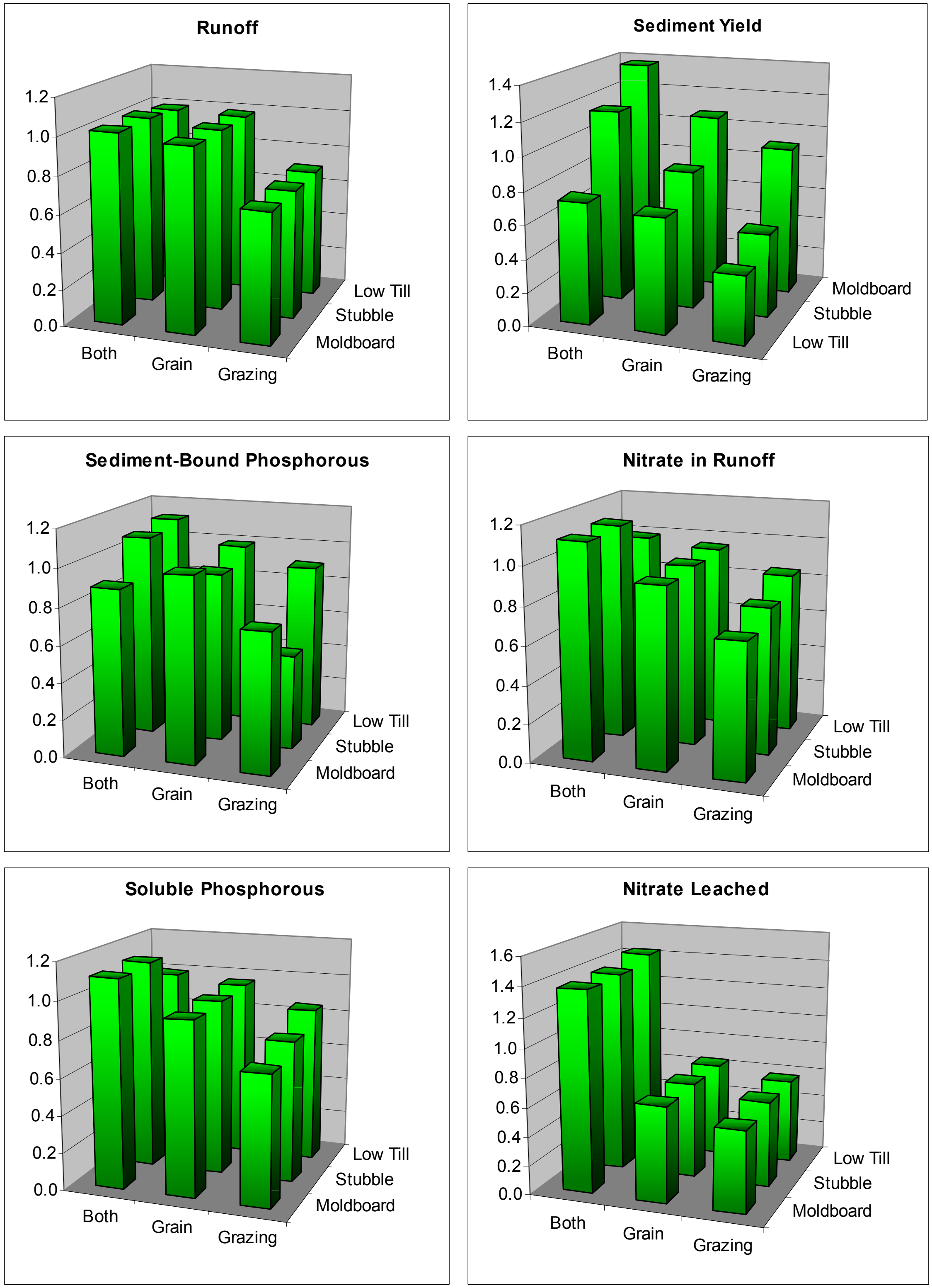



**Figure E3** Relationship among tillage and harvest type for common SWAT model outputs. Displayed as a fraction of calibrated wheat average. Derived from 20-year SWAT simulations.

## Fertilization BMPs

### Nitrogen Fertilization Timing

Nitrogen is typically applied to wheat either pre-plant during summer tillage or topdress in early spring. Anhydrous ammonia is typically the most cost effective choice for pre-plant nitrogen. A granular fertilizer such as ammonium nitrate or urea is typically surface applied in early spring (top-dressing). Top dressing is typically more expensive than a single large anhydrous application, but it allows a farmer to adjust the total nitrogen application rate several months after planting. Unpredictable winter moisture accumulation and changing cattle and grain market conditions often make top-dressing preferable.

Figure E4 contains means and statistical tests performed among different timing scenarios as simulated by SWAT. The all fall application scenario stands out as being quite different from the others, indicating that split applications are preferred to reduce nutrient yields over single large applications.

### Nitrogen Fertilizer Application Rate

The effect of nitrogen application rate on wheat was examined at several different rates in two application scenarios. Nitrogen was applied as either a split application (50% fall, 50% topdress) (Figure E5) or as a single fall application ( Figure E6). Both application methods show increasing nitrogen yields at higher application rates. The rate of increase varies by component from organic nitrogen which displays almost no increase to nitrate leached which show the greatest increase.

### Phosphorous Fertilization Application Rate

Phosphorous applications were simulated at four levels between 15 and 60 lb-$P_2O_5$/acre. A single management (grazing and grain, stubble mulch tillage) was selected to simplify the analysis. The trend lines shown in Figure E7 were very linear ($r^2$> .99). This is likely the result of SWAT`s phosphorous component. SWAT calculates phosphorous yield based on soil phosphorous concentration in the surface layer.

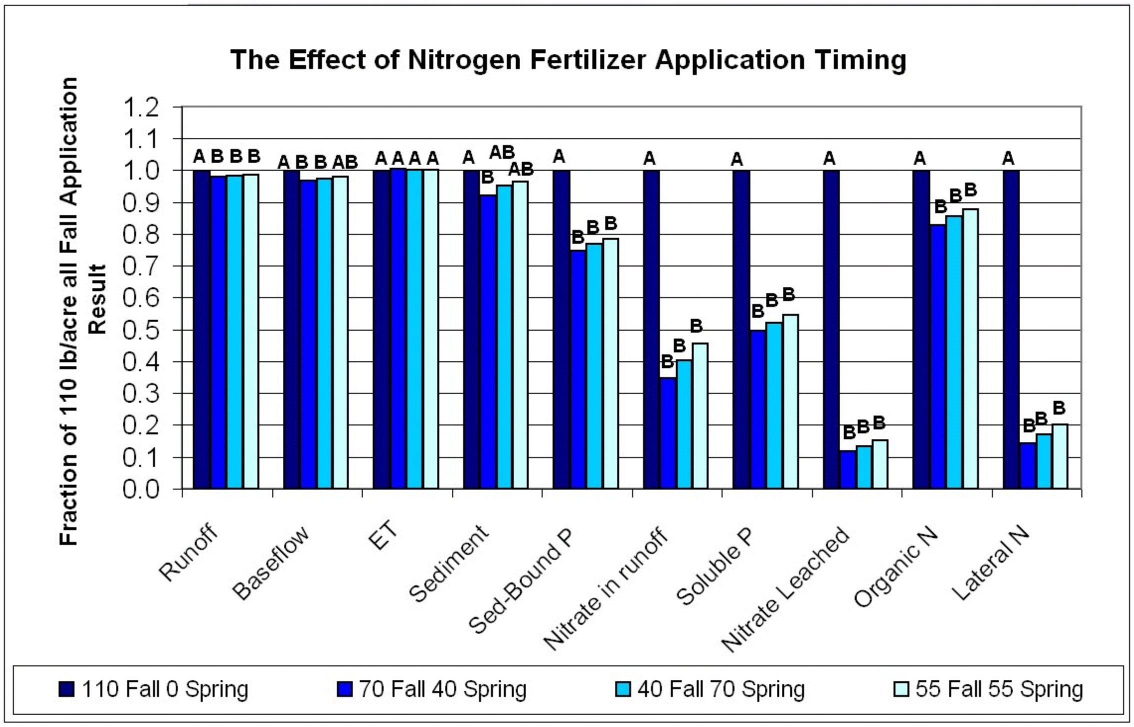



**Figure E4** The effect of nitrogen application timing on the SWAT model. Lettering indicates significant difference among treatments (α = 0.05)**.** Derived from 20-year SWAT simulations.

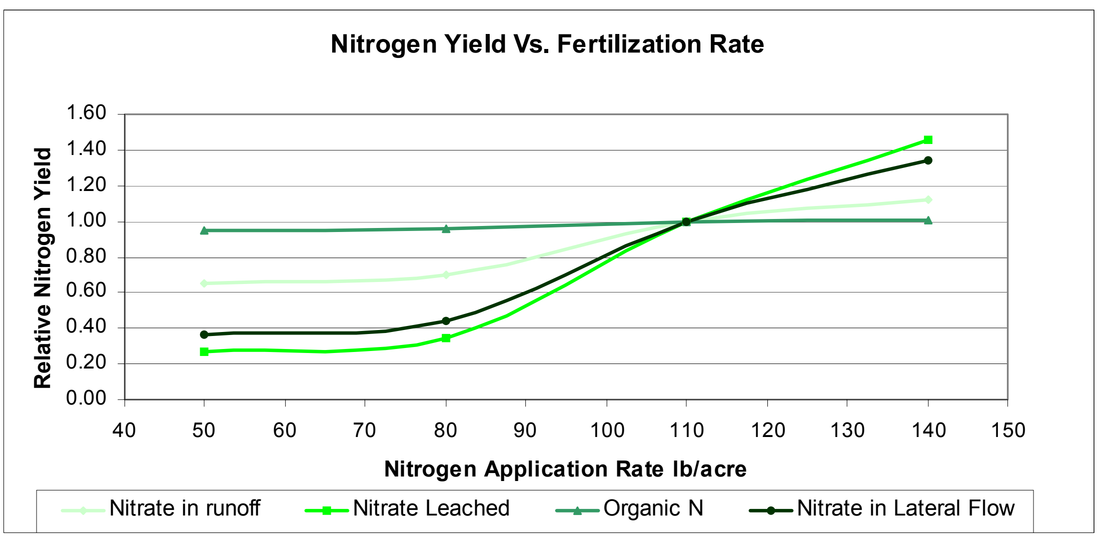



**Figure E5** SWAT predicted nitrogen yield as a function of application rate. Application split 50% preplant 50% topdress, nitrogen yield relative to 110 lb/acre rate. Derived from 20-year SWAT simulations.

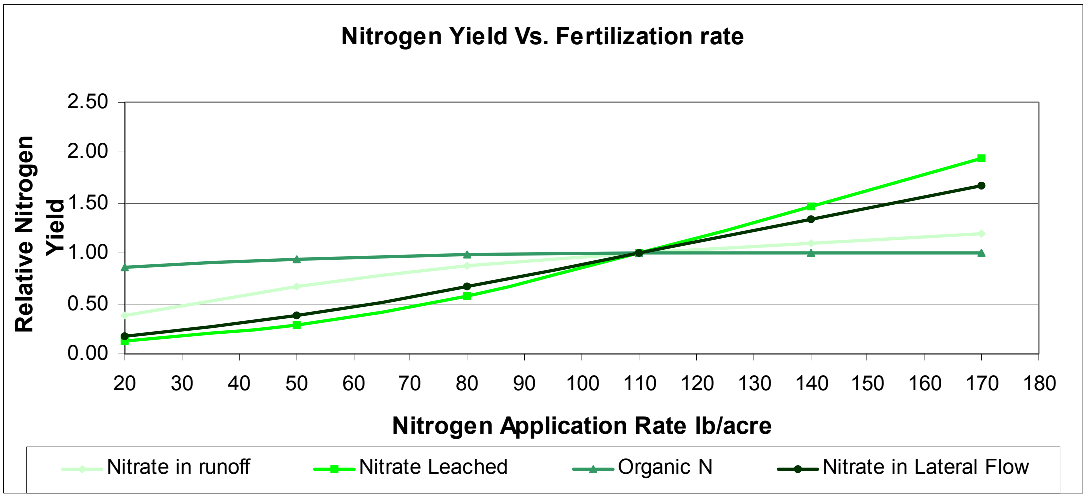



**Figure E6** SWAT predicted nitrogen yield as a function of application rate. Anhydrous ammonia applied preplant, nitrogen yield relative to 110 lb/acre rate. Derived from 20-year SWAT simulations.

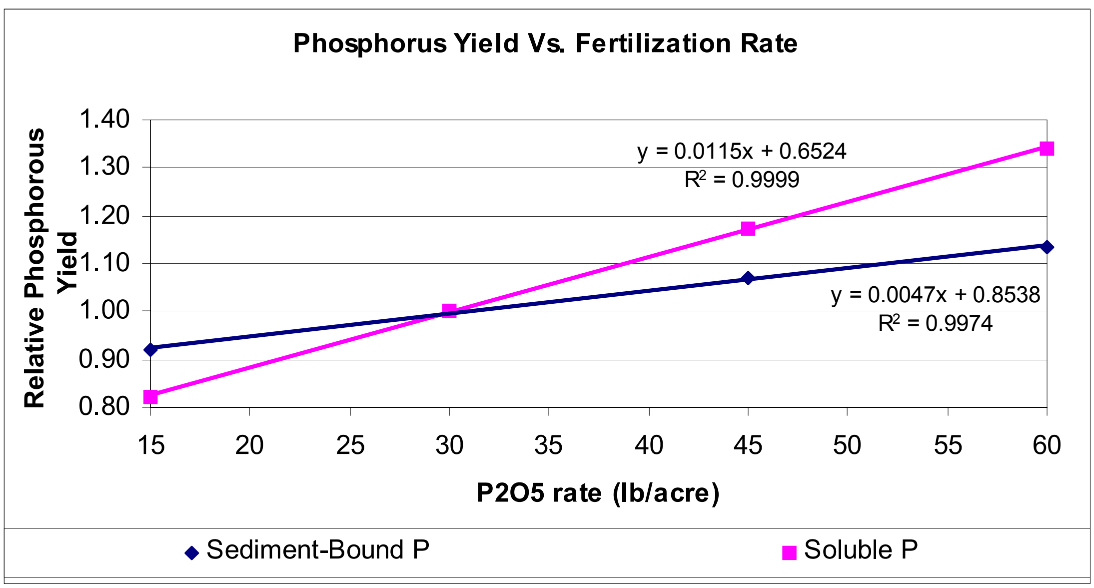



**Figure E7** SWAT predicted phosphorous yield as a function of application rate. Single application before summer tillage, phosphorous yield relative to 30 lb /acre rate. Derived from 20-year SWAT simulations.

## Pesticide BMPs

Pesticides are commonly used on crops in the Great Salt Plains Basin. Herbicides are commonly used on wheat to control cheat grass, and occasionally used on alfalfa. Insecticides are commonly used on alfalfa to treat a variety of pests, but it is seldom profitable to treat wheat for insects. Kenith Fails at the Burlington CO-OP and Jeff Wilber of Wilber Fertilizer Service were contacted to determine the most commonly used pesticides in the area. Application rates were determined from product labels.

Pesticide applications for all fields in the basin were made on a single date in the model. In reality, the timing varies from field to field. This limitation has a greater influence on short duration pesticide yield which are more sensitive to rainfall soon after application.

### Herbicide Application Timing on Wheat

Two herbicides were originally considered for wheat, Maverick™ and Finesse™. Finesse™ was rejected because it has multiple active ingredients, and would dramatically increase modeling difficulty. Maverick™ was applied at a rate of 0.035 kg/ha active ingredient. Applications were made at the following times of year:

1. Preemergence - applied after planting but before wheat seedling emergence.

2. Postemergence Fall - Applied after seedling emergence during November.

3. Postemergence Spring - Applied before jointing stage, during February.

Figures E8 and E9 display simulated herbicide yields at the basin outlet relative to the postemergence scenario. The preemergence application resulted in a very large spike which occurred in October 1995. Examination of the rainfall record indicated several large rainfall events soon after application which could be responsible. Figure E9 shows some years with much smaller pesticide yields; this is thought to be the result of rainfall timing and amount relative to application timing.

### Insecticide Application on Alfalfa

Bathroid™ and Lorsban™ are both commonly applied to alfalfa. Alfalfa is generally treated once each year during March. The exact data of treatment depends on whether the produce uses the calendar or IPM (Integrated Pest Management). Calender applications usually occur in March. IPM applications depend on the level of insect infestation and weather factors, both of which vary from year to year. SWAT does not model insect growth, so a single application date was necessary. Average IPM applications are also in March. The same date was used for both insecticides. The following rates were used:

1. Bathroid™ - 0.0393 kg/ha active ingredient.

2. Lorsban 4E™ - 1.12 kg/ha active ingredient.

Figures E10 and E11 contain simulation results for insecticides used on alfalfa. These data are displayed as a fraction of their respective yield. It is not meaningful to compare two different pesticides relative to each other. These two insecticides show the same relative changes, because of SWAT's simplistic pesticide model and their identical application date. When compared on a non-relative basis, there are orders of magnitude difference between the two insecticides. Figure D11 indicates the majority of insecticide yield occurs in just a few years; presumably the result of rainfall timing and relatively short residue life. Significant yields can only occur when rainfall occurs soon after application, while residue insecticide is still available to runoff.

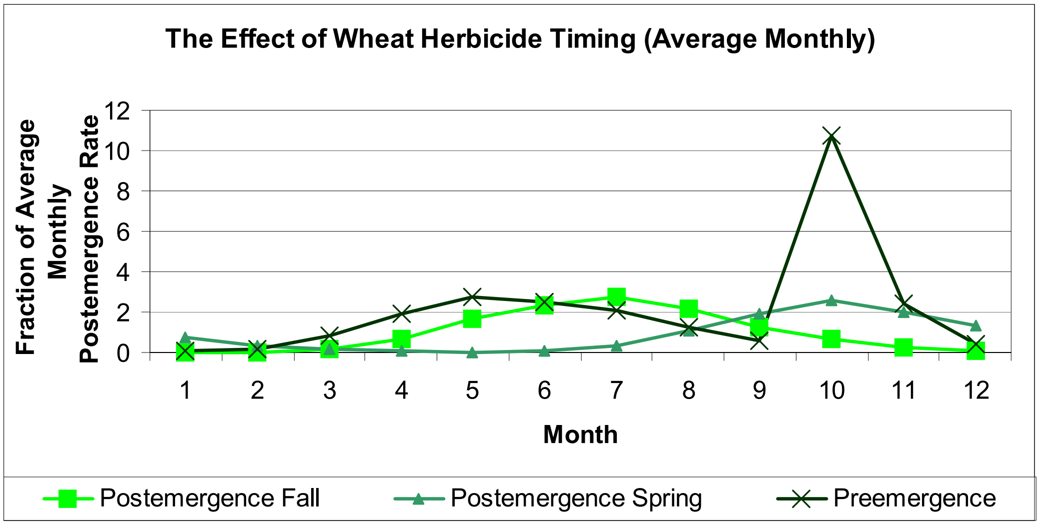



**Figure E8** The effect of wheat herbicide (Maverick™) timing on average monthly pesticide yield. Derived from 20-year SWAT simulations.

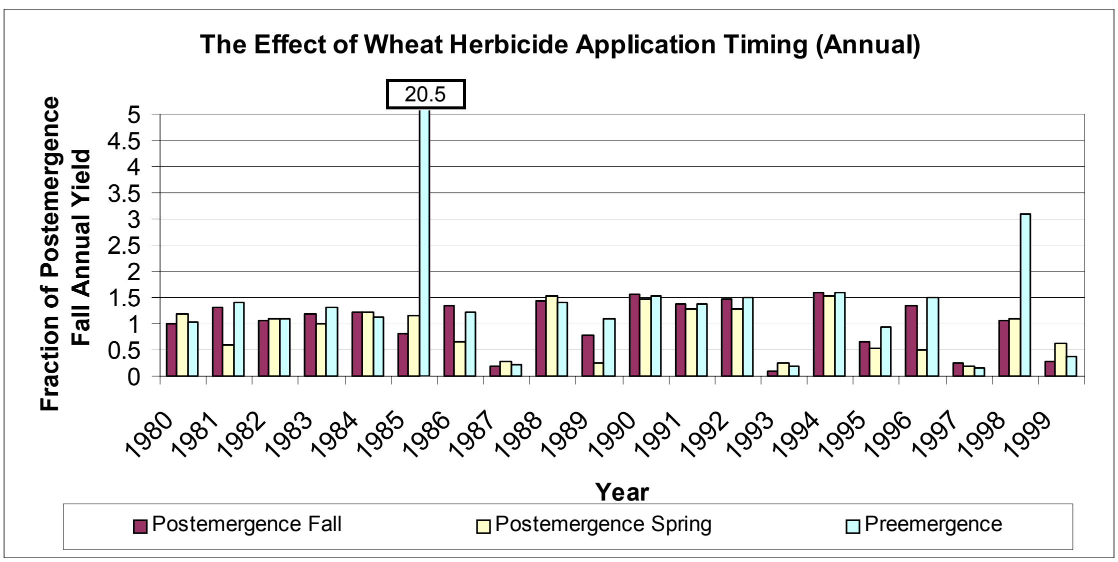



**Figure E9** The effect of wheat herbicide (Maverick™) timing on annual pesticide yield. Derived from 20-year SWAT simulations.

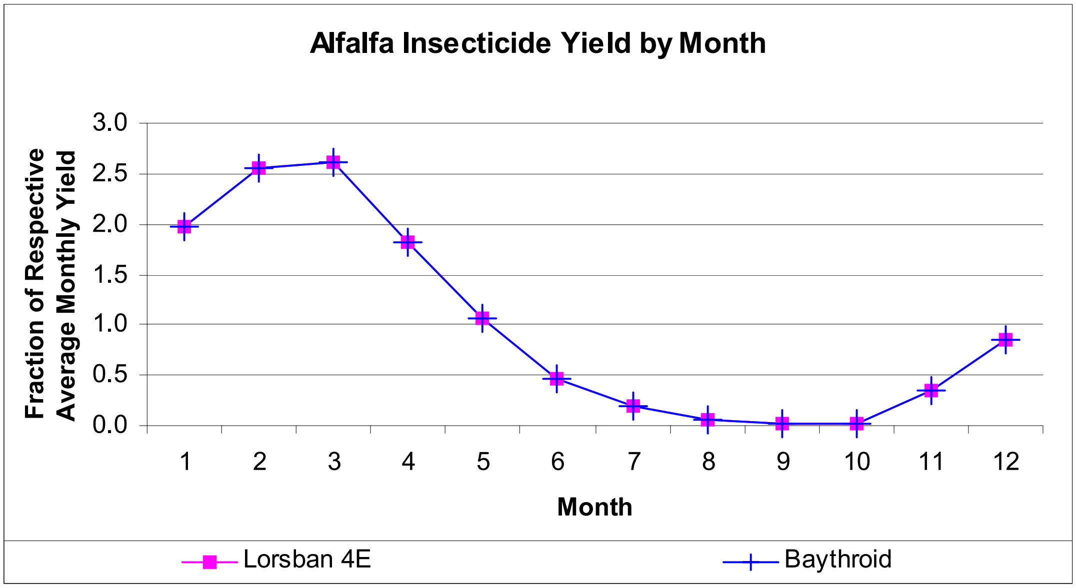



**Figure E10** Alfalfa insecticide yields monthly trends. Derived from 20-year SWAT simulations.

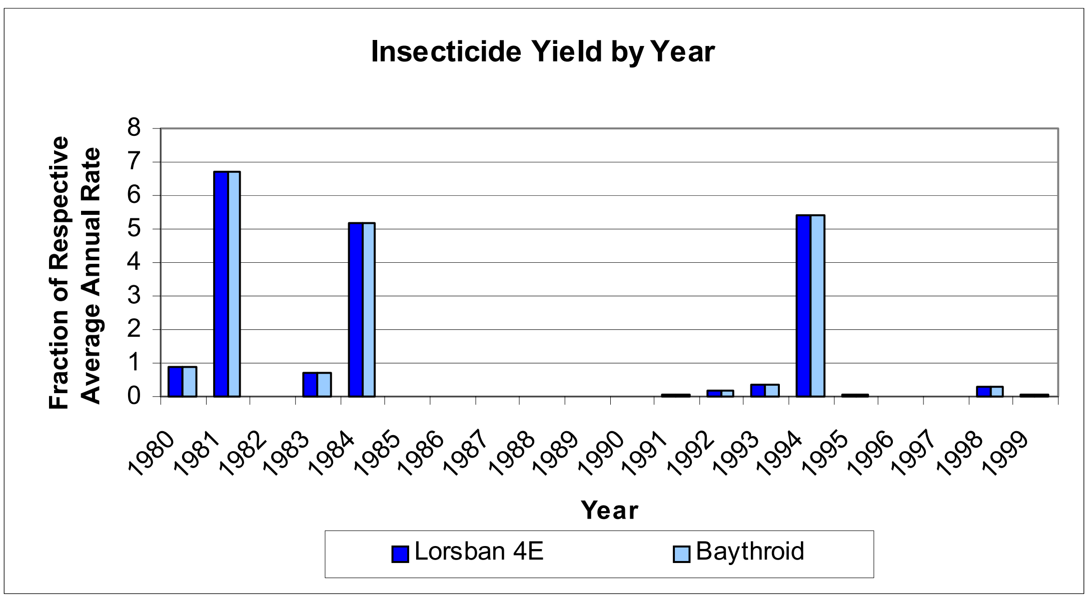



**Figure E11** Alfalfa insecticide annual trends. Derived from 20-year SWAT simulations.

## Sediment Hot Spots

SWAT model predictions and the original high resolution GIS data were used to create a high resolution (30-meter) map of likely high sediment yielding areas (hot spots) (Figure E12).

The land cover and soil combinations from the 50 highest sediment producing HRUs were recorded. Of these 50 HRUs, less that half were unique combinations. The original GIS data were used to determine where in the basin these combinations occur. Simply having a known high sediment yielding land cover and soil combination does not necessarily mean an area is a problem, slope plays a major role. Slope was derived for each pixel using the original 30m DEM. The average slope for all these possible problem areas was used as a cutoff; any area with less than the average slope was removed. Only areas of higher than average slope, and a known high sediment yielding land cover and soil combination remained, referred to as hot spots. The importance of these hot spots was determined by slope, the higher the slope the hotter the spot.

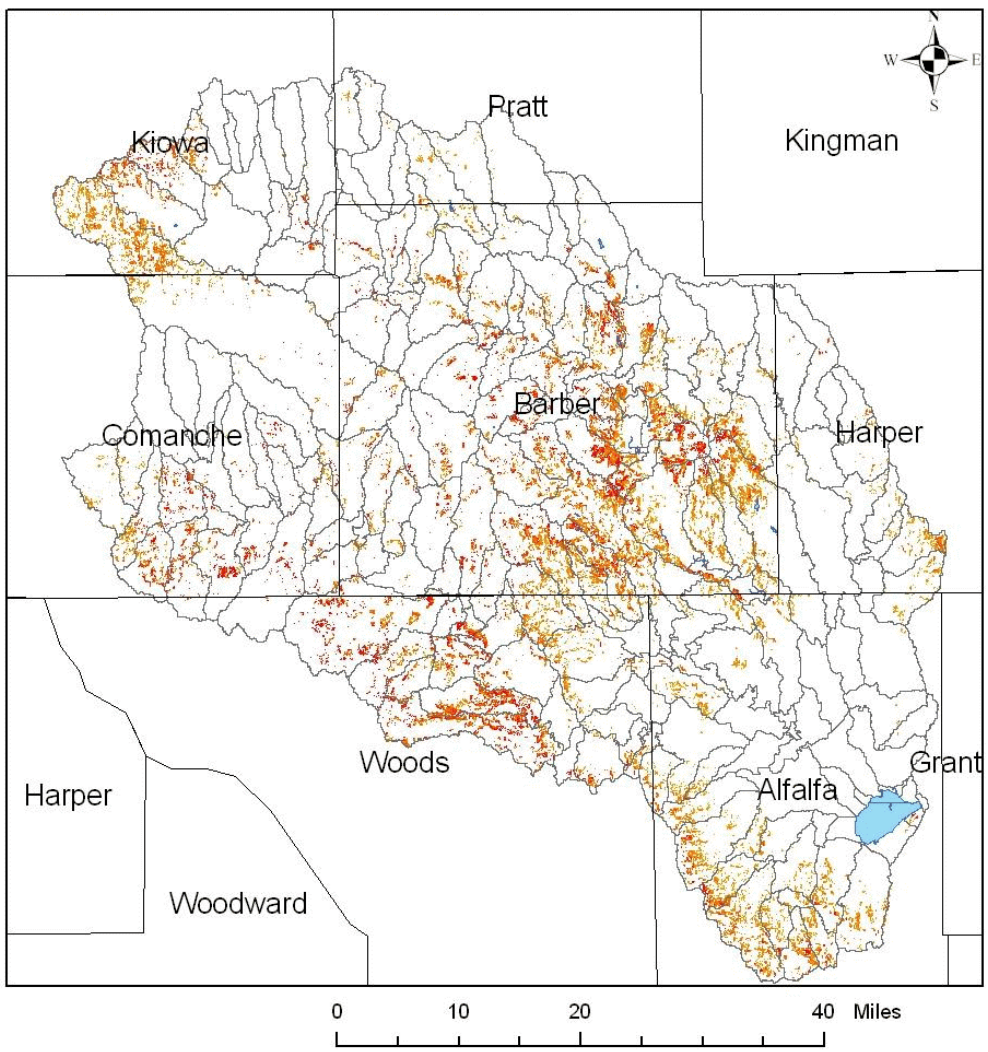



**Figure E12** Sediment hot spots extrapolated from SWAT model output and 30 meter resolution soils, land cover, and DEMs. Darker red indicates higher sediment yield.

# Conclusions

Models can provide a great deal of information not otherwise easily obtained, but it is important that it be used in the proper context. Model results in this report are presented on a relative basis to reduce the uncertainty of these predictions. Actual model output for the calibrated model is given in the appendix, but these data should not be used to make absolute predictions.

A number of important conclusions can be drawn from these simulations:

1. The model indicates 67% of all sediment entering the reservoir comes from wheat fields even though wheat covers only 27% of the basin.
2. Wheat accounts for 92% of all nitrate currently entering the ground water from nonpoint surface sources according to the model.
3. Low till wheat contributes 46% less sediment on average than moldboard tillage when wheat is grazed and harvested for grain in SWAT simulations
4. SWAT estimates 58% of the soluble phosphorous entering the reservoir comes from rangeland. Rangeland covers 66% of the basin.
5. Tillage as simulated by SWAT has little effect on runoff volume.
6. Split nitrogen applications reduce nitrate in surface runoff by more than 55%, and more than 85% in leachate in SWAT simulations.
7. SWAT indicates increased nitrogen fertilizer application results in increased nitrogen losses to both surface and ground water.

## Model limitations

There are several model limitations that should be noted. Model limitation may be the result of data used in the model, inadequacies in the model, or using the model to simulate situations for which it was not designed. Hydrologic models will always have limitations, because the science behind the model is neither perfect nor complete. A model by definition is a simplification of the real world.

Weather is the driving force for any hydrologic model. Great care was taken to include as much accurate observed weather data as possible. The only weather information available was collected at weather stations. Data collected at a few points must be applied to an area of thousands of square miles. Rainfall can be quite variable, especially in the spring when convective thunderstorms produce precipitation with a high degree of spatial variability. It may rain heavily at a weather station, but be dry a short distance away. On an average annual or average monthly basis, these errors have less influence. This limitation among others caution us against using model output on a daily basis or monthly basis.

Scenarios involving radical changes to the basin result in greater uncertainty. The model was calibrated using estimates of what is presently occurring in the basin. Large departures from calibration conditions raise the level of uncertainty.

Land uses that cover only a small area were not represented in the model. Land uses that occupy limited areas such as unpaved roads, bare areas, construction sites, and row crops were not simulated. Most of these features were not depicted in the available land cover. Some of these very small areas may contribute many times more sediment than rangeland of the same area. Although significant, they cannot be simulated with the currently available data.

Each HRU in a subbasin was assumed to have the same characteristics by the model. For instance, the same slope was used for all rangeland and agricultural HRUs in a single subbasin. Agricultural land is generally located in valleys or other flat areas. Rangeland generally occupies land that is unsuitable for agriculture.

There is a great deal of uncertainty associated with management. These simulations assume wheat management is limited to three tillage and three harvest types. In the real world, management varies significantly from field to field; a producer can manage their field any way they wish. It is not possible to easily determine what is happening where, or to simulate all these activities in the model. Therefore, categories were created to cover reasonable managements choices only.

Pesticide application for the basin entire was made on a single date in the model. In reality the timing varies from field to field. This limitation has a greater influence on short duration pesticides yields which are more sensitive to rainfall soon after application. This limitation will cause the model to overestimate the variability of year to year pesticide yields.

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**Table Z1** Example result from the soils matching program. First record is the soil to be matched. Last ten records are candidate soils. Highlighted record is selected as the closest match. Many additional parameters are considered, selected parameters from layer 1 are shown in this example. Standard STATSGO parameter names applied.

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 151BthB2 | OK0059 | C | 85 | OK0059 | 0.37 | 0.2 | 0.6 | 27 | 35 | 1 | 3 | 4 | 0.18 | 0.22 | 1.3 | 1.5 | 100 |
| **MUID** | **SEQNUM** | **Hydgrp** | **Match** | **S5ID** | **KFFACT** | **PERML** | **PERMH** | **CLAYL** | **CLAYH** | **OML** | **OMH** | **LAYDEPH** | **AWCL** | **AWCH** | **BDL** | **BDH** | **NO4L** |
| KS241 | 4 | C | 1000 | OK0059 | 0.43 | 0.60 | 2.00 | 15 | 20 | 1.0 | 3.0 | 14 | 0.16 | 0.24 | 1.30 | 1.50 | 100 |
| KS146 | 14 | C | 959 | MO0020 | 0.37 | 0.20 | 0.60 | 27 | 32 | 1.0 | 3.0 | 6 | 0.18 | 0.20 | 1.35 | 1.50 | 100 |
| KS418 | 15 | C | 940 | TX0250 | 0.32 | 0.20 | 0.60 | 27 | 35 | 1.0 | 3.0 | 6 | 0.12 | 0.18 | 1.30 | 1.45 | 100 |
| KS103 | 1 | C | 936 | MO0001 | 0.37 | 0.20 | 0.60 | 28 | 35 | 1.0 | 4.0 | 11 | 0.18 | 0.20 | 1.35 | 1.45 | 100 |
| KS104 | 13 | C | 932 | KS0072 | 0.37 | 0.20 | 0.60 | 27 | 40 | 2.0 | 4.0 | 9 | 0.21 | 0.23 | 1.35 | 1.45 | 100 |
| KS343 | 9 | C | 926 | KS0200 | 0.32 | 0.20 | 0.60 | 27 | 35 | 1.0 | 2.0 | 6 | 0.21 | 0.23 | 1.30 | 1.40 | 100 |
| KS316 | 5 | C | 918 | KS0019 | 0.37 | 0.20 | 0.60 | 27 | 35 | 2.0 | 4.0 | 14 | 0.21 | 0.23 | 1.30 | 1.40 | 100 |
| OK196 | 15 | C | 917 | OK0204 | 0.37 | 0.20 | 0.60 | 27 | 35 | 0.5 | 2.0 | 7 | 0.15 | 0.20 | 1.30 | 1.60 | 85 |
| KS304 | 6 | C | 912 | KS0213 | 0.37 | 0.20 | 2.00 | 27 | 35 | 1.0 | 3.0 | 7 | 0.21 | 0.23 | 1.35 | 1.45 | 100 |
| KS150 | 1 | C | 911 | OK0015 | 0.37 | 0.20 | 0.60 | 27 | 45 | 1.0 | 4.0 | 13 | 0.16 | 0.20 | 1.25 | 1.50 | 90 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 151BufB | OK0412 | C | 95 | OK0412 | 0.37 | 0.6 | 2 | 18 | 27 | 0.5 | 2 | 6 | 0.15 | 0.24 | 1.4 | 1.55 | 98 |
| **MUID** | **SEQNUM** | **Hydgrp** | **Match** | **S5ID** | **KFFACT** | **PERML** | **PERMH** | **CLAYL** | **CLAYH** | **OML** | **OMH** | **LAYDEPH** | **AWCL** | **AWCH** | **BDL** | **BDH** | **NO4L** |
| KS201 | 12 | C | 921 | KS0050 | 0.37 | 0.60 | 2.00 | 12 | 27 | 0.5 | 1.0 | 8 | 0.22 | 0.24 | 1.25 | 1.35 | 100 |
| KS207 | 7 | C | 920 | AR0093 | 0.43 | 0.60 | 2.00 | 8 | 20 | 1.0 | 3.0 | 9 | 0.14 | 0.20 | 1.25 | 1.45 | 95 |
| OK187 | 1 | C | 919 | TN0055 | 0.43 | 0.60 | 2.00 | 12 | 22 | 1.0 | 4.0 | 8 | 0.17 | 0.22 | 1.30 | 1.40 | 100 |
| OK203 | 6 | C | 914 | LA0014 | 0.49 | 0.60 | 2.00 | 8 | 18 | 0.5 | 2.0 | 2 | 0.15 | 0.22 | 1.35 | 1.65 | 100 |
| OK197 | 17 | C | 910 | OK0204 | 0.43 | 0.60 | 2.00 | 18 | 26 | 0.5 | 2.0 | 7 | 0.15 | 0.24 | 1.30 | 1.55 | 85 |
| OK196 | 6 | C | 910 | OK0133 | 0.43 | 0.60 | 2.00 | 15 | 26 | 0.5 | 2.0 | 9 | 0.13 | 0.22 | 1.30 | 1.60 | 85 |
| OK194 | 5 | C | 907 | OK0208 | 0.43 | 0.60 | 2.00 | 15 | 26 | 0.5 | 2.0 | 9 | 0.10 | 0.16 | 1.30 | 1.60 | 85 |
| OK192 | 7 | C | 901 | OK0230 | 0.43 | 0.60 | 2.00 | 15 | 26 | 0.5 | 2.0 | 8 | 0.13 | 0.24 | 1.30 | 1.55 | 75 |
| OK195 | 5 | C | 901 | OK0227 | 0.43 | 0.60 | 2.00 | 10 | 20 | 0.5 | 2.0 | 7 | 0.13 | 0.20 | 1.30 | 1.60 | 85 |
| OK154 | 7 | C | 901 | TX0265 | 0.49 | 0.60 | 2.00 | 5 | 18 | 0.5 | 1.0 | 10 | 0.12 | 0.16 | 1.45 | 1.60 | 100 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 151BufC | OK0412 | C | 88 | OK0412 | 0.37 | 0.6 | 2 | 18 | 27 | 0.5 | 2 | 7 | 0.15 | 0.24 | 1.4 | 1.55 | 98 |
| **MUID** | **SEQNUM** | **Hydgrp** | **Match** | **S5ID** | **KFFACT** | **PERML** | **PERMH** | **CLAYL** | **CLAYH** | **OML** | **OMH** | **LAYDEPH** | **AWCL** | **AWCH** | **BDL** | **BDH** | **NO4L** |
| KS201 | 12 | C | 925 | KS0050 | 0.37 | 0.60 | 2.00 | 12 | 27 | 0.5 | 1.0 | 8 | 0.22 | 0.24 | 1.25 | 1.35 | 100 |
| KS207 | 7 | C | 923 | AR0093 | 0.43 | 0.60 | 2.00 | 8 | 20 | 1.0 | 3.0 | 9 | 0.14 | 0.20 | 1.25 | 1.45 | 95 |
| OK187 | 1 | C | 920 | TN0055 | 0.43 | 0.60 | 2.00 | 12 | 22 | 1.0 | 4.0 | 8 | 0.17 | 0.22 | 1.30 | 1.40 | 100 |
| OK196 | 6 | C | 914 | OK0133 | 0.43 | 0.60 | 2.00 | 15 | 26 | 0.5 | 2.0 | 9 | 0.13 | 0.22 | 1.30 | 1.60 | 85 |
| OK197 | 17 | C | 913 | OK0204 | 0.43 | 0.60 | 2.00 | 18 | 26 | 0.5 | 2.0 | 7 | 0.15 | 0.24 | 1.30 | 1.55 | 85 |
| OK203 | 6 | C | 912 | LA0014 | 0.49 | 0.60 | 2.00 | 8 | 18 | 0.5 | 2.0 | 2 | 0.15 | 0.22 | 1.35 | 1.65 | 100 |
| OK194 | 5 | C | 910 | OK0208 | 0.43 | 0.60 | 2.00 | 15 | 26 | 0.5 | 2.0 | 9 | 0.10 | 0.16 | 1.30 | 1.60 | 85 |
| OK192 | 7 | C | 904 | OK0230 | 0.43 | 0.60 | 2.00 | 15 | 26 | 0.5 | 2.0 | 8 | 0.13 | 0.24 | 1.30 | 1.55 | 75 |
| OK195 | 1 | C | 904 | OK0279 | 0.43 | 0.60 | 2.00 | 15 | 26 | 0.5 | 2.0 | 9 | 0.10 | 0.16 | 1.30 | 1.60 | 55 |
| OK195 | 5 | C | 903 | OK0227 | 0.43 | 0.60 | 2.00 | 10 | 20 | 0.5 | 2.0 | 7 | 0.13 | 0.20 | 1.30 | 1.60 | 85 |

Relating Soil Test Phosphorous to SWAT Soil Labile P.

The Soil Test P adapted to sol_labp in the .chm. file.

**Sol_labp** = Labile (soluble) P concentration in the surface layer (mg/kg)
**Sol_actp** = Amount of phosphorus stored in the active mineral phosphorus pool? kgP/ha

Default value for Sol_labp is 20 mg/kg

**UNIT Conversions:**

1 lb/acre = 1.12 kg/ha
1 lb P/acre = 1pp2m = 0.5 ppm
1 mg/kg = 1 ppm = 2 lb/acre
Initial value of sol_actp is:
sol_actp = sol_labp* (1. - 0.4) / 0.4) = 1.5 sol_labp >> from source code.
If the soil test value represents the soil labile P pool + soil active P pool then:
Soil test P= 2.5 sol_labp

**Soil test P(lb/acre) = 5 sol_labp (mg/kg)**
This results in the default SWAT soil test P as 100 lb/acre

**Extract from Source Code file, soil_chem.f** (from SWAT model)

```
!!    sol_labp(:,:) |mg/kg      |labile P concentration in soil layer
!!    sol_actp(:,:) |kg P/ha    |amount of phosphorus stored in the
!!                              |active mineral phosphorus pool
if (sol_labp(j,i) > 0.0001) then
        sol_labp(j,i) = sol_labp(j,i) * wt1      !! mg/kg => kg/ha
      else
        !! assume initial concentration of 20 mg/kg
        sol_labp(j,i) = 20. * wt1
      end if
      sol_actp(j,i) = sol_labp(j,i) * (1. - psp) / psp
      sol_stap(j,i) = 4. * sol_actp(j,i)
      sol_hum(j,i) = sol_cbn(j,i) * wt1 * 17200.
      xx = sol_z(j,i)
      summinp = summinp + sol_labp(j,i)
      sumorgp = sumorgp + sol_actp(j,i) + sol_stap(j,i) +
   *       sol_orgp(j,i)
```

**Extract from Source Code file, readbsn.f** (from SWAT model)

```
!!    initialize variables (may make these .bsn inputs for user adjustment
!!    at some future time)
      psp = 0.4
      rtn = 0.20
```

**Table Z2** Calibrated model output by subbasin.

| Subbasin | AREAkm2 | SURQmm | WYLDmm | ETmm | SYLDt/ha | ORGNkg/ha | SEDPkg/ha | NSURQkg/ha | SOLPkg/ha | GW_Qmm |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 40.27 | 47.0 | 76.4 | 625 | 1.71 | 3.69 | 0.88 | 2.51 | 0.13 | 29.1 |
| 2 | 26.93 | 53.5 | 94.6 | 606 | 1.76 | 3.33 | 0.78 | 3.06 | 0.13 | 40.7 |
| 3 | 27.74 | 11.2 | 19.4 | 608 | 0.49 | 0.23 | 0.06 | 0.40 | 0.03 | 7.4 |
| 4 | 33.61 | 8.6 | 9.9 | 617 | 1.02 | 1.77 | 0.50 | 0.41 | 0.02 | 1.2 |
| 5 | 9.88 | 15.6 | 58.2 | 569 | 0.16 | 0.00 | 0.00 | 0.27 | 0.04 | 38.6 |
| 6 | 28.55 | 7.8 | 51.2 | 577 | 0.25 | 0.09 | 0.03 | 0.13 | 0.02 | 37.3 |
| 7 | 39.39 | 20.2 | 33.3 | 592 | 1.73 | 4.17 | 1.05 | 0.93 | 0.05 | 12.2 |
| 8 | 28.50 | 13.9 | 34.8 | 592 | 1.27 | 3.18 | 0.78 | 0.47 | 0.04 | 17.0 |
| 9 | 3.48 | 29.0 | 66.9 | 560 | 1.32 | 0.00 | 0.00 | 1.00 | 0.07 | 31.3 |
| 10 | 17.47 | 23.1 | 84.2 | 543 | 0.79 | 3.25 | 0.69 | 0.63 | 0.03 | 50.5 |
| 11 | 38.99 | 32.0 | 70.8 | 631 | 1.32 | 2.96 | 0.73 | 1.04 | 0.10 | 36.8 |
| 12 | 24.62 | 47.2 | 82.9 | 618 | 3.09 | 7.07 | 1.76 | 2.71 | 0.14 | 34.2 |
| 13 | 0.12 | 29.8 | 175.8 | 526 | 0.23 | 0.00 | 0.00 | 0.81 | 0.08 | 139.0 |
| 14 | 21.31 | 41.0 | 75.0 | 626 | 2.85 | 4.69 | 1.08 | 2.18 | 0.12 | 32.8 |
| 15 | 35.62 | 21.1 | 60.4 | 566 | 0.78 | 3.04 | 0.63 | 0.72 | 0.02 | 36.3 |
| 16 | 88.55 | 23.2 | 57.4 | 562 | 0.96 | 4.35 | 1.04 | 0.72 | 0.04 | 31.8 |
| 17 | 52.47 | 6.8 | 7.9 | 619 | 0.62 | 1.65 | 0.46 | 0.32 | 0.02 | 1.0 |
| 18 | 73.22 | 6.3 | 7.5 | 620 | 0.63 | 1.78 | 0.47 | 0.29 | 0.02 | 0.9 |
| 19 | 64.38 | 21.3 | 35.5 | 590 | 1.82 | 4.66 | 1.19 | 0.94 | 0.05 | 13.0 |
| 20 | 17.68 | 33.3 | 88.0 | 538 | 1.34 | 4.25 | 1.13 | 0.86 | 0.06 | 49.3 |
| 21 | 93.23 | 43.3 | 74.3 | 627 | 2.51 | 6.76 | 1.73 | 2.30 | 0.13 | 30.0 |
| 22 | 60.58 | 49.2 | 65.3 | 636 | 2.58 | 6.87 | 1.80 | 2.79 | 0.15 | 15.8 |
| 23 | 64.73 | 57.1 | 80.9 | 620 | 2.66 | 6.37 | 1.63 | 3.68 | 0.16 | 23.5 |
| 24 | 34.58 | 40.0 | 87.2 | 667 | 1.13 | 4.88 | 1.23 | 1.25 | 0.14 | 44.3 |
| 25 | 10.75 | 29.0 | 73.2 | 554 | 0.85 | 2.76 | 0.88 | 0.57 | 0.07 | 36.8 |
| 26 | 48.02 | 24.5 | 76.1 | 565 | 0.42 | 2.01 | 0.46 | 1.14 | 0.04 | 44.5 |
| 27 | 24.02 | 46.1 | 89.8 | 664 | 2.82 | 5.82 | 1.34 | 1.75 | 0.16 | 42.0 |
| 28 | 16.24 | 36.9 | 88.5 | 666 | 0.65 | 4.70 | 1.24 | 0.79 | 0.13 | 45.7 |
| 29 | 49.25 | 41.4 | 90.2 | 664 | 1.55 | 5.85 | 1.42 | 1.31 | 0.14 | 45.7 |
| 30 | 22.40 | 41.5 | 98.7 | 656 | 1.20 | 5.33 | 1.35 | 1.21 | 0.14 | 50.1 |
| 31 | 63.78 | 42.9 | 81.6 | 620 | 2.31 | 6.78 | 2.48 | 1.31 | 0.13 | 33.6 |
| 32 | 42.31 | 42.6 | 101.7 | 575 | 1.09 | 4.56 | 1.32 | 1.54 | 0.12 | 54.0 |
| 33 | 26.87 | 33.1 | 67.7 | 634 | 1.27 | 5.53 | 1.63 | 1.31 | 0.11 | 29.1 |
| 34 | 5.15 | 45.3 | 52.3 | 629 | 2.17 | 4.94 | 2.67 | 1.87 | 0.17 | 6.8 |
| 35 | 37.10 | 51.8 | 82.8 | 618 | 5.15 | 10.27 | 2.21 | 3.18 | 0.15 | 29.6 |
| 36 | 11.37 | 39.9 | 53.1 | 627 | 1.37 | 5.02 | 1.54 | 2.05 | 0.15 | 12.6 |
| 37 | 2.17 | 55.5 | 161.3 | 591 | 0.60 | 0.00 | 0.00 | 2.49 | 0.21 | 98.4 |
| 38 | 8.82 | 44.3 | 55.5 | 625 | 1.36 | 4.93 | 1.84 | 2.12 | 0.16 | 10.7 |
| 39 | 14.60 | 44.4 | 86.0 | 668 | 2.46 | 5.29 | 1.71 | 1.86 | 0.15 | 36.8 |
| 40 | 23.04 | 38.2 | 90.9 | 663 | 0.87 | 4.58 | 1.19 | 0.95 | 0.14 | 46.1 |
| 41 | 31.01 | 49.7 | 87.2 | 667 | 1.76 | 6.48 | 1.99 | 1.80 | 0.18 | 33.6 |
| 42 | 63.47 | 58.3 | 80.4 | 674 | 3.15 | 9.43 | 2.91 | 2.31 | 0.23 | 20.5 |
| 43 | 49.72 | 27.0 | 78.5 | 602 | 1.14 | 4.60 | 1.89 | 0.98 | 0.09 | 42.4 |
| 44 | 20.22 | 30.1 | 70.8 | 610 | 1.27 | 5.03 | 2.06 | 1.30 | 0.11 | 33.2 |
| 45 | 46.92 | 52.4 | 74.5 | 680 | 2.23 | 7.48 | 2.61 | 1.95 | 0.20 | 20.3 |
| 46 | 8.48 | 68.2 | 89.6 | 664 | 4.56 | 5.18 | 2.33 | 2.83 | 0.25 | 19.9 |
| 47 | 14.51 | 61.4 | 89.1 | 664 | 2.48 | 5.58 | 1.41 | 2.56 | 0.20 | 26.9 |
| 48 | 28.60 | 66.0 | 75.9 | 678 | 3.82 | 6.56 | 4.05 | 2.35 | 0.26 | 9.5 |
| 49 | 44.20 | 47.2 | 81.2 | 674 | 1.09 | 5.66 | 1.94 | 1.44 | 0.18 | 30.1 |
| 50 | 24.25 | 60.7 | 84.7 | 669 | 2.98 | 6.36 | 2.48 | 2.46 | 0.21 | 23.4 |
| 51 | 39.09 | 32.1 | 69.1 | 612 | 1.20 | 5.28 | 1.99 | 1.46 | 0.12 | 30.9 |
| 52 | 55.38 | 62.2 | 98.2 | 656 | 3.33 | 7.08 | 3.66 | 2.12 | 0.24 | 30.2 |
| 53 | 38.29 | 54.3 | 64.1 | 690 | 2.58 | 5.67 | 3.06 | 1.89 | 0.22 | 9.4 |
| 54 | 32.10 | 39.8 | 72.5 | 682 | 1.37 | 4.28 | 1.46 | 1.43 | 0.14 | 31.1 |
| 55 | 53.79 | 50.7 | 84.9 | 669 | 4.10 | 7.10 | 2.67 | 1.66 | 0.16 | 32.3 |
| 56 | 38.97 | 45.3 | 88.8 | 665 | 2.66 | 4.81 | 1.44 | 1.52 | 0.14 | 41.3 |
| 57 | 56.41 | 32.0 | 49.9 | 705 | 1.60 | 4.23 | 1.01 | 1.28 | 0.10 | 15.3 |
| 58 | 25.08 | 44.6 | 70.5 | 681 | 1.18 | 2.03 | 0.50 | 2.16 | 0.11 | 25.1 |
| 59 | 29.26 | 60.1 | 126.6 | 627 | 1.94 | 1.84 | 0.46 | 2.64 | 0.16 | 64.6 |
| 60 | 9.06 | 40.4 | 126.0 | 628 | 2.36 | 0.87 | 0.20 | 1.71 | 0.12 | 80.3 |
| 61 | 39.06 | 32.7 | 58.3 | 715 | 1.39 | 2.23 | 0.62 | 1.26 | 0.09 | 24.1 |
| 62 | 72.11 | 30.6 | 47.7 | 726 | 1.97 | 5.54 | 1.28 | 1.04 | 0.10 | 14.3 |
| 63 | 40.35 | 64.4 | 91.0 | 663 | 3.03 | 6.79 | 3.72 | 2.21 | 0.25 | 23.0 |
| 64 | 25.91 | 68.2 | 78.2 | 676 | 2.99 | 5.99 | 3.33 | 2.37 | 0.25 | 9.7 |
| 65 | 11.04 | 27.8 | 141.7 | 612 | 1.04 | 0.38 | 0.09 | 1.16 | 0.08 | 109.4 |
| 66 | 28.57 | 45.3 | 64.2 | 690 | 3.22 | 5.27 | 3.42 | 1.41 | 0.17 | 17.6 |
| 67 | 78.58 | 30.6 | 59.4 | 714 | 1.96 | 5.06 | 1.32 | 1.10 | 0.10 | 26.3 |
| 68 | 61.77 | 30.2 | 45.1 | 728 | 1.53 | 3.34 | 0.99 | 1.19 | 0.09 | 13.6 |
| 69 | 442.12 | 30.3 | 57.4 | 596 | 2.60 | 5.75 | 1.18 | 1.52 | 0.11 | 23.1 |
| 70 | 43.93 | 16.1 | 27.7 | 653 | 0.55 | 3.12 | 1.03 | 0.70 | 0.06 | 8.1 |

**Table Z2** Calibrated model output by subbasin (continued).

| Subbasin | AREAkm2 | SURQmm | WYLDmm | ETmm | SYLDt/ha | ORGNkg/ha | SEDPkg/ha | NSURQkg/ha | SOLPkg/ha | GW_Qmm |
|---|---|---|---|---|---|---|---|---|---|---|
| 71 | 25.53 | 43.6 | 65.8 | 707 | 1.16 | 0.93 | 0.30 | 1.74 | 0.12 | 21.4 |
| 72 | 20.03 | 39.4 | 58.9 | 714 | 1.42 | 1.09 | 0.34 | 1.65 | 0.11 | 18.7 |
| 73 | 46.39 | 17.8 | 51.8 | 549 | 0.18 | 0.46 | 0.11 | 0.75 | 0.06 | 30.9 |
| 74 | 45.13 | 12.1 | 27.3 | 554 | 0.08 | 0.28 | 0.07 | 0.60 | 0.04 | 13.6 |
| 75 | 23.87 | 55.3 | 112.8 | 641 | 4.42 | 7.42 | 1.90 | 2.32 | 0.16 | 56.2 |
| 76 | 29.27 | 31.8 | 77.3 | 677 | 2.23 | 5.51 | 1.40 | 1.52 | 0.11 | 40.8 |
| 77 | 0.78 | 24.7 | 144.4 | 608 | 0.04 | 0.00 | 0.00 | 0.48 | 0.09 | 118.5 |
| 78 | 44.13 | 51.7 | 76.0 | 678 | 5.40 | 7.91 | 3.05 | 1.83 | 0.18 | 22.8 |
| 79 | 45.01 | 31.3 | 56.8 | 717 | 1.44 | 2.83 | 0.80 | 1.13 | 0.09 | 23.7 |
| 80 | 42.98 | 44.1 | 56.3 | 716 | 0.74 | 0.57 | 0.17 | 1.53 | 0.14 | 11.7 |
| 81 | 58.67 | 29.5 | 68.6 | 612 | 0.60 | 3.06 | 0.91 | 0.80 | 0.09 | 32.0 |
| 82 | 23.00 | 37.3 | 50.8 | 630 | 1.17 | 5.08 | 1.62 | 1.15 | 0.12 | 11.6 |
| 83 | 72.30 | 5.8 | 36.2 | 603 | 0.15 | 0.17 | 0.04 | 0.31 | 0.01 | 22.5 |
| 84 | 7.21 | 4.0 | 14.1 | 667 | 0.02 | 0.00 | 0.00 | 0.12 | 0.02 | 10.0 |
| 85 | 21.08 | 56.9 | 111.5 | 640 | 4.74 | 8.63 | 1.99 | 2.20 | 0.15 | 53.2 |
| 86 | 28.89 | 49.8 | 95.4 | 658 | 5.10 | 8.46 | 2.83 | 1.43 | 0.14 | 42.5 |
| 87 | 40.29 | 42.3 | 59.3 | 715 | 0.94 | 1.29 | 0.42 | 1.43 | 0.13 | 16.3 |
| 88 | 37.14 | 28.8 | 54.5 | 719 | 0.37 | 0.12 | 0.04 | 1.00 | 0.08 | 25.3 |
| 89 | 35.72 | 26.6 | 35.0 | 720 | 2.49 | 5.95 | 1.79 | 0.97 | 0.09 | 7.5 |
| 90 | 59.85 | 25.9 | 44.1 | 711 | 0.86 | 3.91 | 1.03 | 0.78 | 0.10 | 11.7 |
| 91 | 36.22 | 22.0 | 54.2 | 632 | 0.57 | 3.32 | 1.01 | 1.16 | 0.08 | 21.2 |
| 92 | 67.17 | 26.4 | 60.1 | 626 | 0.86 | 4.36 | 1.31 | 1.33 | 0.09 | 26.3 |
| 93 | 12.63 | 17.8 | 63.2 | 618 | 0.58 | 2.51 | 0.80 | 0.41 | 0.06 | 38.2 |
| 94 | 2.16 | 10.7 | 60.5 | 621 | 0.15 | 0.00 | 0.00 | 0.25 | 0.04 | 42.5 |
| 95 | 23.33 | 35.2 | 65.7 | 615 | 1.12 | 5.16 | 1.60 | 1.02 | 0.11 | 23.6 |
| 96 | 1.09 | 1.6 | 66.3 | 615 | 0.01 | 0.00 | 0.00 | 0.03 | 0.01 | 56.7 |
| 97 | 52.71 | 29.2 | 66.7 | 614 | 0.34 | 1.84 | 0.54 | 0.80 | 0.09 | 34.1 |
| 98 | 36.45 | 33.7 | 51.7 | 628 | 0.92 | 3.87 | 1.21 | 1.08 | 0.11 | 16.2 |
| 99 | 23.92 | 20.0 | 41.7 | 639 | 0.46 | 1.70 | 0.53 | 0.58 | 0.06 | 19.6 |
| 100 | 104.52 | 38.9 | 60.1 | 620 | 1.44 | 6.53 | 1.98 | 1.21 | 0.12 | 17.7 |
| 101 | 37.47 | 14.3 | 22.2 | 554 | 0.71 | 0.69 | 0.19 | 1.27 | 0.03 | 7.0 |
| 102 | 62.09 | 26.6 | 41.2 | 588 | 1.32 | 2.73 | 0.69 | 2.75 | 0.06 | 14.4 |
| 103 | 41.80 | 45.7 | 62.2 | 617 | 1.36 | 4.50 | 1.38 | 1.65 | 0.14 | 14.5 |
| 104 | 54.81 | 45.7 | 64.0 | 615 | 1.33 | 3.92 | 1.18 | 1.68 | 0.14 | 17.2 |
| 105 | 25.59 | 27.1 | 60.5 | 620 | 1.20 | 5.04 | 1.52 | 0.90 | 0.09 | 29.4 |
| 106 | 56.32 | 39.3 | 52.9 | 628 | 1.21 | 4.41 | 1.46 | 1.90 | 0.12 | 12.5 |
| 107 | 40.45 | 20.8 | 56.7 | 624 | 0.26 | 1.02 | 0.30 | 0.65 | 0.07 | 31.8 |
| 108 | 14.80 | 28.7 | 44.3 | 637 | 0.67 | 2.60 | 0.82 | 1.00 | 0.09 | 13.8 |
| 109 | 0.00 | 2.8 | 105.6 | 576 | 0.01 | 0.00 | 0.00 | 0.06 | 0.01 | 98.8 |
| 110 | 42.08 | 17.7 | 22.0 | 552 | 0.87 | 1.96 | 0.50 | 1.13 | 0.05 | 3.7 |
| 111 | 54.75 | 31.9 | 46.3 | 633 | 1.78 | 5.45 | 1.66 | 1.19 | 0.10 | 12.6 |
| 112 | 43.73 | 15.2 | 24.4 | 654 | 1.10 | 3.57 | 0.92 | 0.57 | 0.05 | 8.7 |
| 113 | 4.62 | 4.6 | 75.3 | 612 | 0.11 | 0.00 | 0.00 | 0.12 | 0.01 | 62.6 |
| 114 | 43.58 | 28.3 | 39.5 | 647 | 0.93 | 3.75 | 1.24 | 1.58 | 0.09 | 8.9 |
| 115 | 22.80 | 30.3 | 48.7 | 637 | 1.08 | 4.69 | 1.47 | 1.02 | 0.10 | 17.0 |
| 116 | 34.75 | 28.9 | 47.1 | 638 | 1.33 | 5.33 | 1.63 | 0.84 | 0.09 | 16.2 |
| 117 | 39.08 | 13.6 | 82.3 | 713 | 0.13 | 0.00 | 0.00 | 0.34 | 0.03 | 61.5 |
| 118 | 26.44 | 32.1 | 54.2 | 741 | 0.57 | 0.23 | 0.08 | 0.83 | 0.11 | 21.4 |
| 119 | 33.45 | 48.3 | 62.6 | 623 | 1.69 | 5.44 | 1.74 | 2.63 | 0.14 | 13.4 |
| 120 | 18.00 | 21.0 | 31.9 | 654 | 0.55 | 2.91 | 0.94 | 1.17 | 0.08 | 10.4 |
| 121 | 13.38 | 20.8 | 68.4 | 727 | 0.52 | 0.17 | 0.04 | 0.57 | 0.06 | 45.5 |
| 122 | 39.51 | 31.8 | 64.4 | 730 | 1.07 | 2.75 | 0.77 | 1.40 | 0.10 | 31.3 |
| 123 | 39.61 | 16.3 | 37.1 | 649 | 0.25 | 1.47 | 0.46 | 1.02 | 0.07 | 14.8 |
| 124 | 54.66 | 38.4 | 47.5 | 639 | 1.37 | 4.72 | 1.84 | 2.18 | 0.12 | 7.8 |
| 125 | 55.78 | 21.8 | 33.9 | 737 | 1.59 | 4.38 | 1.06 | 0.88 | 0.05 | 11.7 |
| 126 | 8.62 | 27.3 | 84.0 | 676 | 1.39 | 0.69 | 0.13 | 1.18 | 0.07 | 53.2 |
| 127 | 2.20 | 19.1 | 97.5 | 676 | 0.23 | 0.00 | 0.00 | 0.49 | 0.04 | 76.1 |
| 128 | 36.40 | 16.0 | 24.9 | 744 | 0.85 | 2.22 | 0.53 | 0.70 | 0.04 | 8.8 |
| 129 | 168.74 | 37.0 | 75.3 | 611 | 1.37 | 3.87 | 1.44 | 0.94 | 0.09 | 19.6 |
| 130 | 0.87 | 16.2 | 91.0 | 595 | 0.04 | 0.00 | 0.00 | 0.37 | 0.05 | 69.7 |
| 131 | 75.25 | 34.9 | 46.1 | 639 | 1.07 | 3.95 | 1.31 | 1.99 | 0.11 | 9.5 |
| 132 | 13.75 | 29.3 | 34.1 | 652 | 0.89 | 4.20 | 1.39 | 1.00 | 0.11 | 4.5 |
| 133 | 21.62 | 24.2 | 118.3 | 677 | 0.20 | 0.00 | 0.00 | 0.76 | 0.05 | 91.0 |
| 134 | 53.18 | 31.3 | 73.2 | 721 | 0.95 | 2.35 | 0.64 | 1.41 | 0.09 | 39.4 |
| 135 | 45.60 | 28.3 | 48.2 | 710 | 3.38 | 6.17 | 1.44 | 1.29 | 0.08 | 19.1 |
| 136 | 32.89 | 19.8 | 33.1 | 724 | 1.93 | 4.23 | 0.87 | 1.10 | 0.05 | 13.0 |
| 137 | 90.73 | 12.7 | 22.1 | 662 | 1.26 | 3.47 | 0.90 | 0.68 | 0.04 | 8.5 |
| 138 | 61.80 | 26.8 | 46.9 | 712 | 2.93 | 5.64 | 1.29 | 1.22 | 0.07 | 19.0 |
| 139 | 9.52 | 21.7 | 47.9 | 636 | 2.24 | 2.58 | 0.79 | 1.12 | 0.06 | 23.0 |
| 140 | 31.21 | 21.2 | 40.0 | 645 | 1.74 | 4.07 | 0.98 | 0.99 | 0.06 | 16.3 |

**Table Z2** Calibrated model output by subbasin (continued).

| Subbasin | AREAkm2 | SURQmm | WYLDmm | ETmm | SYLDt/ha | ORGNkg/ha | SEDPkg/ha | NSURQkg/ha | SOLPkg/ha | GW_Qmm |
|---|---|---|---|---|---|---|---|---|---|---|
| 141 | 116.96 | 24.5 | 89.5 | 684 | 0.30 | 0.40 | 0.14 | 0.79 | 0.07 | 59.6 |
| 142 | 151.52 | 20.4 | 32.2 | 738 | 1.36 | 4.15 | 1.06 | 0.77 | 0.05 | 11.6 |
| 143 | 34.56 | 51.2 | 83.8 | 778 | 2.54 | 7.46 | 1.95 | 1.45 | 0.16 | 32.5 |
| 144 | 47.43 | 12.6 | 24.9 | 731 | 0.47 | 1.24 | 0.31 | 0.81 | 0.03 | 12.3 |
| 145 | 30.46 | 18.7 | 34.5 | 721 | 0.67 | 1.68 | 0.43 | 1.14 | 0.05 | 15.7 |
| 146 | 122.41 | 18.7 | 30.1 | 723 | 2.42 | 6.50 | 1.45 | 0.64 | 0.05 | 10.7 |
| 147 | 32.78 | 50.5 | 107.2 | 653 | 3.26 | 5.18 | 1.46 | 1.99 | 0.15 | 52.3 |
| 148 | 51.34 | 35.9 | 66.1 | 619 | 1.39 | 4.02 | 1.41 | 1.29 | 0.10 | 13.5 |
| 149 | 22.10 | 44.2 | 70.0 | 615 | 1.56 | 3.88 | 1.21 | 1.67 | 0.12 | 8.1 |
| 150 | 36.88 | 49.4 | 62.8 | 698 | 5.03 | 7.43 | 3.21 | 2.23 | 0.19 | 12.6 |
| 151 | 61.96 | 19.9 | 36.3 | 720 | 1.58 | 4.01 | 0.91 | 1.13 | 0.05 | 16.2 |
| 152 | 35.43 | 51.8 | 102.0 | 657 | 2.07 | 2.52 | 0.83 | 2.43 | 0.12 | 49.5 |
| 153 | 1.35 | 21.9 | 37.1 | 722 | 1.22 | 0.00 | 0.00 | 1.11 | 0.05 | 14.7 |
| 154 | 9.89 | 23.0 | 41.4 | 716 | 1.31 | 1.37 | 0.34 | 1.44 | 0.06 | 18.2 |
| 155 | 33.89 | 52.9 | 98.1 | 764 | 1.08 | 1.48 | 0.38 | 1.63 | 0.18 | 44.3 |
| 156 | 78.60 | 21.9 | 149.9 | 691 | 0.24 | 0.30 | 0.09 | 0.33 | 0.07 | 118.4 |
| 157 | 17.18 | 49.6 | 82.4 | 780 | 2.80 | 4.93 | 1.26 | 1.24 | 0.16 | 32.6 |
| 158 | 40.31 | 66.9 | 112.2 | 751 | 3.99 | 10.15 | 2.54 | 2.08 | 0.19 | 45.1 |
| 159 | 59.35 | 28.5 | 51.2 | 708 | 1.57 | 3.45 | 0.96 | 0.84 | 0.11 | 19.2 |
| 160 | 57.52 | 54.7 | 62.7 | 697 | 7.58 | 8.58 | 2.61 | 2.94 | 0.21 | 7.8 |
| 161 | 73.02 | 59.2 | 100.1 | 762 | 2.09 | 5.36 | 1.40 | 1.43 | 0.20 | 40.0 |
| 162 | 75.97 | 44.7 | 73.9 | 788 | 1.30 | 3.85 | 1.03 | 1.14 | 0.15 | 29.2 |
| 163 | 33.93 | 53.0 | 93.2 | 769 | 1.20 | 2.73 | 0.77 | 1.42 | 0.19 | 39.9 |
| 164 | 4.22 | 87.1 | 173.9 | 690 | 0.70 | 0.00 | 0.00 | 3.72 | 0.27 | 82.6 |
| 165 | 33.13 | 61.4 | 111.7 | 751 | 0.59 | 0.48 | 0.12 | 1.44 | 0.26 | 49.8 |
| 166 | 44.19 | 62.5 | 100.3 | 762 | 1.22 | 1.79 | 0.45 | 1.72 | 0.24 | 37.1 |
| 167 | 26.35 | 53.4 | 99.7 | 762 | 1.28 | 1.44 | 0.41 | 1.44 | 0.20 | 46.0 |
| 168 | 2.11 | 67.7 | 156.6 | 706 | 0.36 | 0.00 | 0.00 | 2.13 | 0.22 | 87.9 |
| 169 | 30.52 | 20.7 | 40.1 | 716 | 0.59 | 1.38 | 0.35 | 1.34 | 0.06 | 19.2 |
| 170 | 11.73 | 26.3 | 66.3 | 693 | 1.23 | 1.01 | 0.22 | 1.10 | 0.08 | 37.3 |
| 171 | 11.45 | 34.2 | 69.2 | 691 | 1.37 | 0.19 | 0.05 | 1.49 | 0.09 | 33.3 |
| 172 | 29.17 | 22.7 | 45.5 | 749 | 1.42 | 4.11 | 1.14 | 1.30 | 0.08 | 21.6 |
| 173 | 22.38 | 32.5 | 60.7 | 697 | 0.80 | 1.03 | 0.29 | 1.65 | 0.08 | 27.5 |
| 174 | 36.55 | 27.8 | 47.9 | 711 | 1.68 | 2.91 | 0.73 | 1.02 | 0.08 | 18.9 |
| 175 | 70.90 | 53.4 | 110.1 | 752 | 1.89 | 4.69 | 1.35 | 1.38 | 0.22 | 55.5 |
| 176 | 20.43 | 57.1 | 84.8 | 777 | 2.52 | 4.97 | 1.41 | 1.87 | 0.19 | 27.6 |
| 177 | 42.36 | 22.2 | 132.3 | 708 | 0.27 | 0.07 | 0.02 | 0.28 | 0.07 | 102.7 |
| 178 | 21.38 | 19.8 | 147.7 | 693 | 0.24 | 0.00 | 0.00 | 0.23 | 0.07 | 110.2 |
| 179 | 105.03 | 36.4 | 45.2 | 714 | 6.86 | 9.04 | 2.78 | 1.89 | 0.14 | 8.2 |
| 180 | 25.08 | 47.5 | 118.7 | 642 | 1.73 | 1.17 | 0.32 | 1.93 | 0.13 | 67.7 |
| 181 | 41.01 | 49.3 | 81.0 | 782 | 3.68 | 10.09 | 2.39 | 1.47 | 0.16 | 31.5 |
| 182 | 74.93 | 58.2 | 90.6 | 772 | 4.12 | 11.63 | 2.73 | 1.71 | 0.21 | 32.0 |
| 183 | 4.58 | 32.8 | 143.4 | 697 | 0.07 | 0.00 | 0.00 | 0.45 | 0.11 | 76.8 |
| 184 | 0.08 | 0.0 | 143.4 | 697 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.0 |
| 185 | 15.83 | 27.1 | 135.4 | 705 | 0.07 | 0.00 | 0.00 | 0.52 | 0.12 | 27.1 |
| 186 | 30.31 | 58.0 | 109.9 | 729 | 0.02 | 0.00 | 0.00 | 1.05 | 0.31 | 3.3 |
| 187 | 85.99 | 74.0 | 99.5 | 762 | 1.55 | 4.09 | 1.18 | 2.20 | 0.29 | 25.4 |
| 188 | 9.15 | 88.0 | 136.1 | 726 | 0.46 | 0.00 | 0.00 | 2.54 | 0.35 | 33.7 |
| 189 | 0.32 | 29.6 | 125.8 | 728 | 0.00 | 0.00 | 0.00 | 0.52 | 0.17 | 0.0 |
| 190 | 42.03 | 40.1 | 151.3 | 689 | 0.26 | 0.03 | 0.02 | 0.92 | 0.15 | 55.5 |
| 191 | 29.28 | 57.3 | 96.4 | 766 | 2.14 | 4.96 | 1.46 | 1.87 | 0.19 | 39.1 |
| 192 | 37.10 | 84.8 | 152.4 | 712 | 3.12 | 7.06 | 2.01 | 3.65 | 0.26 | 66.4 |
| 193 | 50.07 | 47.8 | 83.8 | 729 | 0.99 | 2.25 | 0.64 | 1.78 | 0.16 | 29.4 |
| 194 | 70.42 | 51.9 | 98.8 | 713 | 1.43 | 3.74 | 1.15 | 2.28 | 0.17 | 44.3 |
| 195 | 31.66 | 32.8 | 53.5 | 742 | 1.79 | 3.93 | 1.21 | 1.92 | 0.11 | 20.2 |
| 196 | 73.96 | 68.4 | 99.7 | 713 | 3.10 | 6.43 | 2.18 | 2.58 | 0.23 | 30.3 |
| 197 | 22.32 | 48.1 | 78.0 | 733 | 1.96 | 3.57 | 1.06 | 1.92 | 0.15 | 29.2 |
| 198 | 8.29 | 38.9 | 65.5 | 743 | 1.44 | 2.59 | 0.72 | 1.91 | 0.12 | 26.2 |
| 199 | 27.42 | 65.4 | 89.5 | 724 | 2.79 | 6.44 | 1.99 | 2.45 | 0.23 | 23.0 |
| 200 | 22.52 | 43.1 | 69.5 | 743 | 2.82 | 7.30 | 1.86 | 1.90 | 0.15 | 24.7 |
| 201 | 16.51 | 17.7 | 34.6 | 652 | 0.18 | 1.32 | 0.36 | 0.54 | 0.06 | 14.3 |
| 202 | 12.92 | 49.7 | 137.0 | 725 | 1.70 | 1.10 | 0.26 | 1.28 | 0.17 | 85.5 |
| 203 | 41.40 | 76.8 | 103.6 | 758 | 0.04 | 0.00 | 0.00 | 1.38 | 0.41 | 22.2 |
| 204 | 49.02 | 34.6 | 114.2 | 727 | 0.08 | 0.01 | 0.01 | 0.55 | 0.16 | 68.8 |
| 205 | 0.08 | 58.0 | 108.3 | 731 | 0.00 | 0.00 | 0.00 | 1.00 | 0.31 | 0.0 |
| 206 | 0.12 | 38.6 | 333.8 | 506 | 0.00 | 0.00 | 0.00 | 0.44 | 0.12 | 245.9 |
| 207 | 91.48 | 51.6 | 121.6 | 630 | 2.89 | 7.54 | 1.81 | 2.39 | 0.14 | 68.6 |
| 208 | 0.07 | 28.0 | 190.1 | 571 | 0.41 | 0.00 | 0.00 | 0.50 | 0.08 | 135.1 |
| 209 | 15.41 | 46.9 | 75.9 | 684 | 1.53 | 2.01 | 0.58 | 0.71 | 0.11 | 26.9 |
| 210 | 1.99 | 34.6 | 132.0 | 709 | 0.71 | 0.00 | 0.00 | 0.39 | 0.07 | 63.8 |

## SAS Programs

SAS program written to analyze fertilizer timing model simulations.

```
*FILENAME timing.SAS;

DATA ONE;

INFILE 'A:TIMING.TXT';
INPUT year TRT$ SURQ GWQ ET SYLD SEDP NSURQ SOLP NO3L Orgn LATN;

*PROC PRINT;

PROC MIXED;
CLASS YEAR TRT;
MODEL SURQ = TRT/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TRT/DIFF;

PROC MIXED;
CLASS YEAR TRT;
MODEL GWQ = TRT/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TRT/DIFF;

PROC MIXED;
CLASS YEAR TRT;
MODEL ET = TRT/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TRT/DIFF;

PROC MIXED;
CLASS YEAR TRT;
MODEL SYLD = TRT/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TRT/DIFF;

PROC MIXED;
CLASS YEAR TRT;
MODEL SEDP = TRT/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TRT/DIFF;

PROC MIXED;
CLASS YEAR TRT;
MODEL NSURQ = TRT/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TRT/DIFF;

PROC MIXED;
CLASS YEAR TRT;
MODEL SOLP = TRT/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TRT/DIFF;

PROC MIXED;
CLASS YEAR TRT;
MODEL NO3L = TRT/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TRT/DIFF;

PROC MIXED;
CLASS YEAR TRT;
MODEL Orgn = TRT/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TRT/DIFF;

PROC MIXED;
CLASS YEAR TRT;
MODEL LATN = TRT/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TRT/DIFF;

RUN;
```

SAS program written to analyze tillage/harvest type model simulations.

```
*FILENAME STATS.SAS;

DATA ONE;

INFILE 'A:STATS.PRN';
INPUT year Tillage$ grazing$ PRCP SURQ GWQ ET SYLD SEDP NSURQ SOLP NO3L Orgn LATN;

*PROC PRINT;

PROC MIXED;
CLASS YEAR TILLAGE GRAZING;
MODEL PRCP = TILLAGE|GRAZING/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TILLAGE*GRAZING/SLICE=(TILLAGE GRAZING) DIFF;
LSMEANS TILLAGE GRAZING/DIFF;

PROC MIXED;
CLASS YEAR TILLAGE GRAZING;
MODEL SURQ = TILLAGE|GRAZING/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TILLAGE*GRAZING/SLICE=(TILLAGE GRAZING) DIFF;
LSMEANS TILLAGE GRAZING/DIFF;

PROC MIXED;
CLASS YEAR TILLAGE GRAZING;
MODEL GWQ = TILLAGE|GRAZING/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TILLAGE*GRAZING/SLICE=(TILLAGE GRAZING) DIFF;
LSMEANS TILLAGE GRAZING/DIFF;

PROC MIXED;
CLASS YEAR TILLAGE GRAZING;
MODEL ET = TILLAGE|GRAZING/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TILLAGE*GRAZING/SLICE=(TILLAGE GRAZING) DIFF;
LSMEANS TILLAGE GRAZING/DIFF;

PROC MIXED;
CLASS YEAR TILLAGE GRAZING;
MODEL SYLD = TILLAGE|GRAZING/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TILLAGE*GRAZING/SLICE=(TILLAGE GRAZING) DIFF;
LSMEANS TILLAGE GRAZING/DIFF;

PROC MIXED;
CLASS YEAR TILLAGE GRAZING;
MODEL NSURQ = TILLAGE|GRAZING/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TILLAGE*GRAZING/SLICE=(TILLAGE GRAZING) DIFF;
LSMEANS TILLAGE GRAZING/DIFF;

PROC MIXED;
CLASS YEAR TILLAGE GRAZING;
MODEL SOLP = TILLAGE|GRAZING/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TILLAGE*GRAZING/SLICE=(TILLAGE GRAZING) DIFF;
LSMEANS TILLAGE GRAZING/DIFF;

PROC MIXED;
CLASS YEAR TILLAGE GRAZING;
MODEL NO3L = TILLAGE|GRAZING/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TILLAGE*GRAZING/SLICE=(TILLAGE GRAZING) DIFF;
LSMEANS TILLAGE GRAZING/DIFF;

PROC MIXED;
CLASS YEAR TILLAGE GRAZING;
MODEL Orgn = TILLAGE|GRAZING/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TILLAGE*GRAZING/SLICE=(TILLAGE GRAZING) DIFF;
LSMEANS TILLAGE GRAZING/DIFF;

PROC MIXED;
```

SAS program written to analyze tillage/harvest type model simulations (Continued).

```
CLASS YEAR TILLAGE GRAZING;
MODEL LATN = TILLAGE|GRAZING/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TILLAGE*GRAZING/SLICE=(TILLAGE GRAZING) DIFF;
LSMEANS TILLAGE GRAZING/DIFF;

RUN;
```

**Table Z3** High sediment yielding soil and land cover combinations. Soils classified by STATSGO (State Soil Geographic) database MUID (Map Unit IDentification) and sequence.

| Soil | Land cover |
|---|---|
| KS201_12 | WWT |
| KS506_8 | WWT |
| OK072_1 | WWT |
| OK088_3 | WWT |
| OK108_6 | WWT |
| TN042_6 | WWT |
| TX265_1 | WWT |
| TX268_2 | WWT |
| TX273_3 | WWT |
| TX432_9 | WWT |
| TX524_8 | WWT |
| TX524_8 | WWT |
| KS245_2 | SOYB |
| OK072_1 | SOYB |
| OK088_3 | SOYB |
| OK108_6 | SOYB |
| OK213_14 | SOYB |
| TX268_2 | SOYB |